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THESIS

EELV SECONDARY PAYLOAD ADAPTER (ESPA) RING: OVERCOMING CHALLENGES TO ENABLE RESPONSIVE SPACE

by

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September 2011

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Technology advancement is a primary goal for military space development. By staying ahead of the competition, space systems can offer unique battlefield capabilities. A number of space programs are increasingly behind schedule, over budget, and underperforming. This thesis explains the benefits the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring can offer programs experiencing technical immaturity or desiring responsive space. By understanding and adhering to the ESPA Rideshare Users Guide and the Auxiliary Payload Interface Control Document, programs desiring a ride aboard an ESPA-configured EELV will achieve greater success and have fewer issues in the launch vehicle-to-satellite integration process.

The Government Accountability Office (GAO) has published many reports offering proven process requirements that will result in increasing the odds of program success. By studying the benefits an ESPA ring offers, many processes recommended by the GAO can be implemented resulting in better cost and schedule performance. The research performed involves launch vehicles and their current state, along with a description of rideshare integration. The analytical results, along with findings of successful and struggling space programs, are then used to show how the ESPA system can advance program readiness from the laboratory to the operational environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

AATS	Assured Access To Space
AEHF	Advanced Extremely High Frequency
AFRL	Air Force Research Laboratory
APL	Auxiliary Payload
ASAP 5	Ariane Structure for Auxiliary Payload 5
ASAP	Ariane
ASTRO	Autonomous Space Transport Operations
ATP	Authority To Proceed
CFESat	Cibola Flight Experiment Satellite
CLSRB	Current Launch Schedule Review Board
CITRIS	Scintillation and Tomography Receiver
COMSTAC	Commercial Space Transportation Alliance
COTS	Commercial off the shelf
DARPA	Defense Advanced Research Projects Agency
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DSCS	Defense Satellite Communications System
DSS	Dual Spacecraft System
EELV	Evolved Expendable Launch Vehicle
ELC	EELV Launch Capability
ESA	European Space Agency
ESPA	EELV Secondary Payload Adapter
GAO	Government Accountability Office
GPS	Global Positioning System
GSE	Ground Support Equipment
GSO	Geosynchronous Orbit
GTO	Geostationary Transfer Orbit
IPC	Integrated Payload Carrier
IRRT	Independent Readiness Review Team
ISR	Intelligence, Surveillance, and Reconnaissance
ISS	International Space Station
KPP	Key Performance Parameters
lb	Pound
LCROSS	Lunar Crater and Observation and Sensing Satellite

LRO	Lunar Reconnaissance Orbiter
LRSD	Launch and Range Systems Directorate
LV	Launch Vehicle
LVC	Launch Vehicle Contractor
MEMS	Micro-Electro-Mechanical System
MEPSI	MEMS PicoSat Inspector
MP3	Moving Picture Experts Group Layer-3
NASA	National Aeronautics and Space Administration
NextSat	Next Generation Serviceable Satellite
NGSO	Non-Geosynchronous Orbit
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRO	National Reconnaissance Office
ORS	Operationally Responsive Space
PPF	Payload Processing Facility
P-Pod	Poly Picosatellite Orbital Deployer
PWR	Pratt and Whitney Rocketdyne
S&T	Science and Technology
SBIR	Small Business Innovation Research
SBIRS	Space Based Infrared System
SDTD	Space Development and Test Directorate
SHIMMER	Spatial Heterodyne Imager for Mesospheric Radicals
SHS	Spatial Heterodyne Spectroscopy
SMC	Space and Missile Systems Center
SPELTRA	Structure Porteuse Externe Lancement TRiple Ariane
STP	Space Test Program
STP-1	Space Test Program-1 (first ESPA mission)
STPsat-1	Space Test Program Satellite-1
SV	Satellite Vehicle
SYLDA 5	Système de Lancement Double Ariane 5
TCC	Type-C Carrier
TRL	Technology Readiness Level
TSAT	Transformational Satellite Communications System
U.S.	United States
ULA	United Launch Alliance
USB	Universal Serial Bus

I. INTRODUCTION

A. BACKGROUND

Operations in outer space have dramatically advanced since the launch of Sputnik in 1957. These missions have been so successful that in just a few decades society has become dependent on the benefits space assets offer. The navigation, communication, and weather monitoring benefits offered by satellites impact everyone's daily lives. Every time a person uses the Internet, pays for gas, processes a bank transaction, or uses a navigation system, space assets are relied upon. These assets have become nearly transparent in United States society as efficient time-saving resources. Most people do not realize the extent to which they rely on space. Even some military members fail to appreciate completely their reliance on space. A quote is used in the military community in which a Soldier says, "I don't need space systems; all I need is this little box which tells me where to go." This statement shows how it is possible to forget that the Global Positioning System (GPS) is a complex 24+ satellite constellation operating within tight orbital and timing tolerances. With the great advances in satellites, it seems launch vehicles (LVs) would have changed drastically also, but they have really changed very little since the 1960s. The main reason for the apparent lack in evolution of launch vehicles is the extreme difficulty and complexity of achieving orbit. When Sputnik launched, the satellite itself was not so remarkable; it was a 184-pound basketball-sized sphere with a beeping transmitter placed inside. What made the launch so amazing was that the Soviet Union created a launch vehicle with enough thrust to push past the bounds of earth's atmospheric drag and accelerate fast enough to achieve stable orbit.

When discussing today's launch vehicles, the concept and designs are the same, but improvements in engine performance have enabled vehicles to deliver a 47,522-pound satellite into a Low Earth Orbit (LEO). Such a feat is achieved through a launch vehicle that delivers approximately 1,950,000 pounds of thrust at liftoff [1]. For the United States, this launch capability is provided by the EELV Delta IV launch vehicle in the heavy configuration, which uses three Pratt and Whitney Rocketdyne (PWR) RS-68A

engines on the first stage. The remarkable brute force achievement of entering space was and is still accomplished through heavy, high-thrust, highly combustible launch vehicles. Just as a highly trained athlete makes sports look easy, launch experts make launches look repetitively simple, yet launches continue to be the greatest challenge of today's space missions. Figure 1 is from Major General Ellen Pawlikowski's article presented in *High Frontier* magazine entitled "Mission Assurance—A Key Part of Space Vehicle Launch Mission Success [2]." This figure shows the greatest risk to a satellite occurs during launch pad operations, launch, and activation. The risk is so great because launches operate in the small space between a controlled explosion and imminent detonation. Use of a proven vehicle, such as EELV, can reduce these risks to the payloads. This study examines the launch vehicles currently used and discusses the benefits of the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring. The ESPA ring enables a launch vehicle to deliver up to six secondary payloads to orbit, in addition to the primary payload normally carried by the launcher.

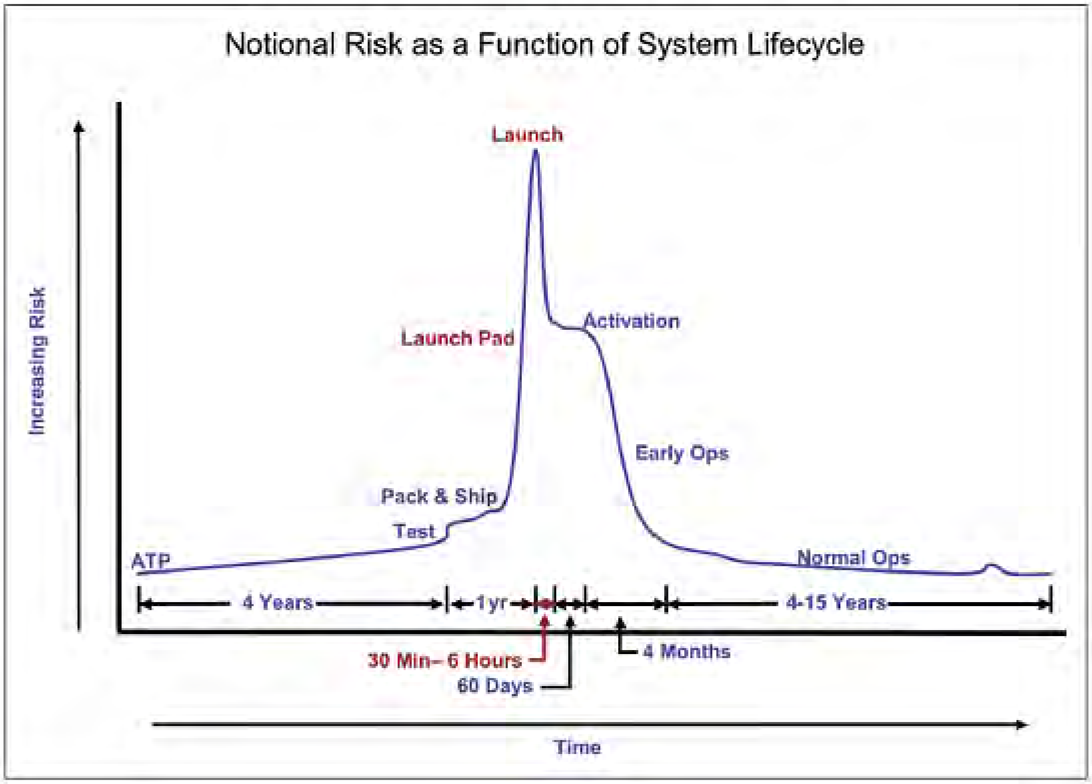

Figure 1. Notional Risk as a Function of Systems Life cycle [From 2]

The ESPA ring is being embraced by the scientific community according to Lt. Col. Dan Griffith, Director Space Test Program, Kirtland AFB, who said, “there is a lot of interest in ESPA across the space community and the interest is growing. It was designed primarily with the science and technology community in mind, but there are very obvious potential applications if you have a small operational satellite. No reason why they could not use an ESPA ring [3].” The utility of delivering one primary and six secondary satellites to orbit offers a greatly reduced cost and brings additional benefits. However, it seems the primary payload provider is having a difficult time appreciating what ESPA offers due to the perceived increase in system integration complexity potentially leading to more mission risk. The goal of this paper is to explain ESPA’s benefits and illustrate that once the initial developmental phase passes, the utility of the ESPA ring will be as a system integrated standard launch service offering “plug-and-play” secondary payload deployments for the majority of future launch missions.

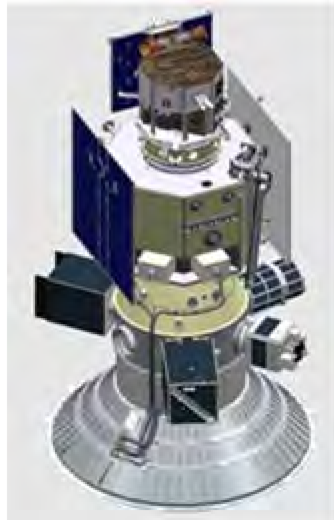

Figure 2. ESPA Drawing

In the middle 1990s, launch vehicle costs were estimated at $9,000 per pound for payload to orbit. Thus, if a program wished to launch a 10,000-pound satellite, the launch vehicle and integration expenses would be expected to cost $90M. During this time, forecasted analysis predicted a drastic increase in demand for launch vehicles. Many experts predicted the launch industry to operate 85 launches a year. This drove many analysts to predict the cost per pound to drop drastically (to as low as $400 per pound), since demand would drive down individual supply costs. There were projected "demands for launch services at prices as low as $400/lb in the 2010 to 2030 time period. The number of flights was projected to rise to as many as 250/year; about one per business day" [4]. A reduction in launch costs of this magnitude would increase the corporate demand for satellite constellations allowing many companies to use satellites as their primary programs of development and system augmentation. The exact opposite occurred. Companies found terrestrial systems to perform their missions and launch vehicles failed to achieve great cost reductions, so the forecasted demand never materialized. What produced the greatest setback in launch cost reductions was that many activities required to support the enormous forecasted launch demand had already been initiated. Launch companies began to spend great amounts of capital to build vehicles and infrastructures capable of supporting such a vigorous launch rate. The U.S. program fell

under the Air Force initiative called the EELV program, which produced two highly capable launch vehicles in the medium to heavy lift arena. The launch vehicles are known as Atlas V and Delta IV and are the most robust, highest producing, and capable launch vehicles ever designed by the United States. Currently, the Department of Defense (DoD) is attempting to find solutions to augment or support the high costs associated with both vehicles and their infrastructure. In [5] "Officials specifically cited the unmanned Atlas and Delta rockets, saying their costs could soar in the next few years due to underutilized industrial capabilities and high vendor overhead." Much of the market analysis is predicting that costs could double over the next few years [5].

The capability of the launch vehicles to integrate and execute missions carrying the ESPA ring is only the initial start. The future goal is to make the capability a standardized launch service aboard the majority of all missions manifested, which will allow many programs to deploy new, faster, smaller satellites into orbit, leading to a dramatic increase in technological maturity. With the announcement and activation of a new Operationally Responsive Space (ORS) office on 21 May 2007 [6], the Air Force intends to make space access faster and cheaper. One of the ORS office's first tasks laid out the vision, mission, and goals of the new office. They submitted the *2007 Plan for Operationally Responsive Space: A Report to Congressional Defense Committees* [7], which details the plans for a tier-level execution approach. Along with the ORS office, many universities, companies, and corporate programs see benefits in what the ESPA ring can offer through penetration of the barriers to launch.

The ESPA ring not only offers the capability for manifesting science experiments and limited-funded programs, but it can significantly accelerate the acquisition process. A comparison of today's satellites to the massive computers of the 1960s reveals much of the same limitations in performance, cost, and mass. Following this trend, the future generations of satellites should evolve to offer more capabilities in a smaller, greatly reduced cost package, similar to today's desktops. Currently, the typical satellites vary from the size of a car to a bus, whereas future satellites will offer the same or better performance in much smaller packages. Transforming space into a network of smaller,

more flexible and responsive space assets will bring about a new leap in technology and evolutionary advancement. This ability to deliver smaller more responsive satellites would change the arena of space. "But the need for systems that don't take a decade to develop and deliver, and can survive an attack, or be quickly replaced, is driving the trend toward smaller spacecraft [8]."

B. PURPOSE

This research is intended to provide an understanding of the benefits and concerns associated with the ESPA ring's integration into future EELV missions. It will also help define the proper steps needed to standardize the ESPA mission integration processes, Auxiliary Payload (APL) standardization/testing requirements, and future employment of the ESPA system. The research will identify any valid systemic issues associated with the ESPA system. Additional objectives include detailing the standardization processes required and validating the system for safe deployment of the secondary payloads on a noninterference basis with the primary payload, which will benefit U.S. space programs. The final objective is to explain the documentation required for ESPA integration to assist program managers vying for a ride.

C. RESEARCH QUESTIONS

This paper addresses the primary question: Can the ESPA ring be so clearly defined and implemented that it becomes nearly transparent to the primary payload, making integration simple enough to gain program manager support and offer more frequent research and scientific missions to orbit? Answering this overarching question will simultaneously answer each of the following specific research questions.

- Does the decrease in cost for the secondary payloads outweigh the mission integration difficulties?
- Is it possible for a late APL to be replaced by its mass model without causing expensive coupled loads reanalysis?
- What is the reality when it comes to primary mission risk and APL failures?

- What steps can be developed to make APL integration standardized among the smaller satellites?
- Can timelines be reduced for APL integration to increase responsiveness to space?
- Is it possible to have "hot spare" APLs ready to go in the event a manifested APL is not ready without causing expensive launch reanalysis?

D. BENEFITS OF STUDY

This study attempts to provide specific recommendations to the U.S. Air Force and DoD to utilize the benefits the ESPA ring can offer in the areas of operational capabilities, acquisition reform, scientific research, and Technology Readiness Level (TRL) advancement. The ESPA ring is currently in the initial phases of acceptance within the space acquisition process. By resolving issues and addressing doubt, this study can help the ESPA ring provide the needed progress in scientific research and maturing technological development activities before programs attempt to implement them into their systems.

E. SCOPE

This thesis explains the design and integration of the ESPA ring onto EELV rockets. It also discusses the risks and apprehensions of using an ESPA ring, and illustrates risk reduction activities, creating a system that is nearly seamless for the primary payload. This thesis also explains methods to reduce mission integration risks and standardize the requirements of the secondary payloads. The paper is not scoped to discuss in detail the financial expense or corporate direction of space acquisition. It does not examine in detail the differences between the U.S.-built EELV launch systems and the European Ariane 5 vehicle, but it will discuss some of the decisions made by the two corporations and the lessons learned.

F. METHODOLOGY

The methodology used to develop this research began with conducting a literature review of the objectives and requirements required for successful APL–ESPA–LV integration. This baseline research then became the foundation upon which the

appreciation for secondary payload challenges can best be addressed. Furthermore, a review of the current documents designed to standardize and simplify the ESPA integration became the basis for requirement understanding. Next, a review of the history of launch systems was conducted to examine critical occurrences which would reveal whether the ESPA ring was beneficial to Assured Access to Space (AATS). A thorough review and analysis was then conducted on the current and future missions utilizing the ESPA ring, examining the benefits that each mission offered to the scientific and government communities. After the previous data was analyzed, a brief review of the participating organizations and their involvement in the ESPA development. All of the data was then analyzed from the perspective of the overall and subordinate research questions and conclusions were developed.

G. THESIS ORGANIZATION

From this point forward, the thesis is organized as follows. Chapter II discusses the launch vehicle history and describes some of the events that occurred in the 1990s, such as the forecasted booming launch vehicle demand, which failed to materialize. The chapter then compares and contrasts the Arianespace Ariane Vs launch vehicle and secondary payload adapters versus the EELV launch vehicles and ESPA ring. The chapter also contains a review of the current space acquisition programs and processes continuing to fall behind cost, schedule, and performance margins. Finally, the chapter concludes with a description of the ESPA ring design and satellite configuration possibilities, along with a discussion of ORS and Technology Readiness Levels (TRLs).

Chapter III contains the results of literature research on specific missions, which have either used or plan to use the ESPA ring. It also describes the integration process foreseen for the ESPA missions, and it contains the documentation and current program offices, which are developing the ESPA policies.

Chapter IV uses the highly successful CubeSat program as a model for proper guideline development. This chapter also takes the space acquisition discussion, literature reviews, mission designs and ESPA documentations from Chapters II and III to present

the steps and processes being implemented to make rideshare possible. The documents discussed in this section will be the qualification steps ensuring secondary payloads are adequately prepared for mission integration.

Chapter V analyses the current status of the United States Air Force space programs and provides recommendations based on the research findings in Chapter IV. Finally, Chapter V includes several suggestions for further study.

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II. BACKGROUND ON LAUNCH VEHICLE AND ESPA SYSTEMS INFLUENCING THE SPACE ACQUISITION PROCESS

A. INTRODUCTION

Before explaining the ESPA system and integration challenges, an analysis of the historical evolution of the launch industry, followed by a review of the current state of space acquisitions, must be discussed. It is well known that almost every space program initiative is experiencing high cost growth and delays in program milestones [9]. The U.S. Air Force heavily funds space programs, which can be broken into Intelligence, Surveillance, and Reconnaissance (ISR), Weather, Missile Warning, Communication, and Navigation missions. In every area, a major failure in program management, cost growth, schedule delays, and capability reductions have been experienced within the last decade. Three highly visibility programs, which received Nunn-McCurdy breaches due to their system costs reaching a threshold greater than 25%, are the Space Based Infrared System (SBIRS) program, Advanced Extremely High Frequency (AEHF) system, and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Each of these programs has become an example of the pitfalls involved in an acquisition initiative. The intent of an overview of the space acquisition process is to illuminate the U.S. and DoD developmental activities and issues in regards to program execution and probability of system success.

Before discussing the state of space acquisitions and ways in which ESPA may significantly reduce the cost growth, it is first necessary to look at the launch industry and examine what caused the demand for launch vehicles to evaporate and the launch costs to skyrocket. In the early 1990s, a strong belief existed that launch demand would continue to rise. In 2002, the 1998 launch forecast predicted approximately 80–85 launches would occur; and the reality was in the order of 24 launches for 2002. What impacts did the forecast of 80–85 launches versus the realized 24 launches cause? The next section answers this question.

B. LAUNCH HISTORY AND CURRENT VEHICLE SYSTEMS

1. History of Launch Systems

In the early 1990s, many believed the Commercial Space Transportation Alliance (COMSTAC) performed highly credible launch forecast initiatives. The results of the alliance were reports anticipating launch rates quadrupling the current launch rate for geosynchronous orbit (GSO) and non-geosynchronous orbit (NGSO) launches [10]. This COMSTAC information led to industry experts foreseeing huge delays and loss of profits coming for the current launch systems. Solidifying the concerns were reports outlining the deficiencies predicted in launch capabilities for the 21st century. Determined to mitigate bottlenecks, initiatives were taken to upgrade and fund new launch systems capable of handling the foretelling tempo. This opened a door for the U.S. and European launch industries to realize a profit from an industry typically too expensive to properly sustain; by gaining the majority of the future market shares, profits could finally be realized.

The COMSTAC report was highly regarded because it was performed by industry without the direct intent to persuade. The authors of the COMSTAC report used realistic market data and information to form a legitimate prediction of future launch demands [10]. The COMSTAC group was comprised of the Boeing Defense and Space Group, General Dynamics Space Systems Division, Lockheed Missiles and Space Company, Martin Marietta Astronautics, McDonnell Douglas Aerospace, and Rockwell Space Systems Division. The study attempted to calculate the launch demand based on current satellite developmental activities, which forecasted a major growth for commercial and military space systems. Figure 3 is from the COMSTAC May 2008 Commercial Space Transportation Forecasts report [10], which shows the trend of launch forecasts from 1998–2006 compared to the actual data from 2007. When reviewing the 1998 data (note arrow), it is easy to see what spawned the race to develop highly reliable, capable, launch systems, which would be required to keep up with the demand. If the 1998 data were somewhat accurate, a severe deficiency in launch vehicles would be realized in 2002.

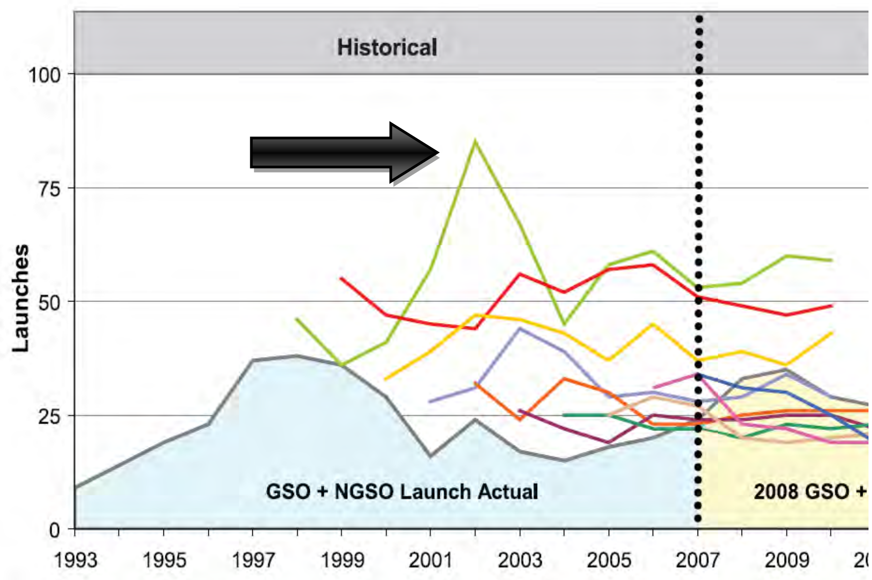
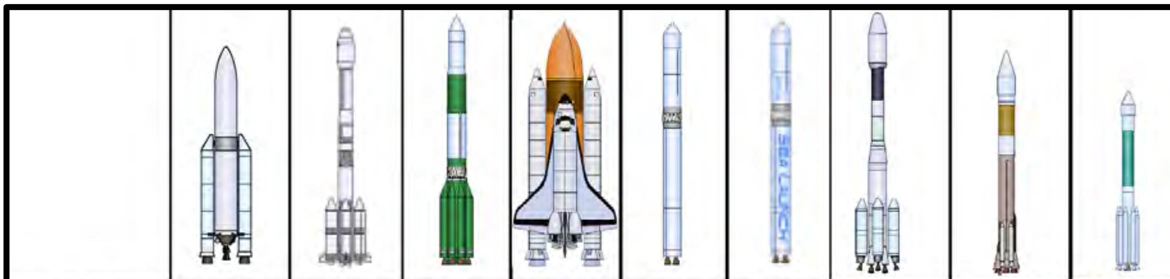


Figure 3. COMSTAC Launch Prediction [From 10]

Following an explosion of heavy funding and rapid vehicle evolutionary activities, the systems were ready for service. The U.S.-built Atlas V and Delta IV vehicles, along with Europe's Ariane 5, were ready to carry the industry's satellites to orbit. The manifest never grew as predicted. Instead, it left some very expensive vehicles and supporting infrastructure performing at only a quarter of their capacity. What happened? "It was later determined that many decisions regarding the future use of space and how to develop new vehicles to get there [were] based more on wishful thinking and overly optimistic technological assessments rather than on rigorous economic analysis" [4]. What was believed to be highly regarded data coming from the COMSTAC group was actually less financially driven and more "wishful thinking" of what constellations of communication, weather, and imagery systems could be. This oversight of not considering the business aspect of the customer drove the misdirection for space launch capacity. Almost all reports showed the launch industries' costs decreasing substantially. Some forecasted launch costs were as low as $400/lb whereby today's launch costs range about $4,000/lb for LEO satellites, and $10,000/lb for Geostationary (GEO) satellites

[11]. Figure 4 offers a historical illustration to show the capabilities and costs of a few international and domestic medium to heavy lift vehicles available during the early 2000s. [11].



Vehicle name	Ariane 5G	Long March 3B	Proton	Space Shuttle	Zenit 2	Zenit 3SL	Ariane 44L	Atlas 2AS	Delta 2 (7920/5)
Country/Region of origin	Europe	China	Russia	USA	Ukraine	Multinational	Europe	USA	USA
LEO capacity lb (kg)	39,648 (18,000)	29,956 (13,600)	43,524 (19,760)	63,443 (28,803)	30,264 (13,740)	34,969 (15,876)	22,467 (10,200)	18,982 (8,618)	11,330 (5,144)
Reference LEO altitude km (mi)	342 (550)	124 (200)	124 (200)	127 (204)	124 (200)	124 (200)	124 (200)	115 (185)	115 (185)
GTO capacity lb (kg)	14,994 (6,800)	11,466 (5,200)	10,209 (4,630)	13,010 (5,900)	0	11,576 (5,250)	10,562 (4,790)	8,200 (3,719)	3,969 (1,800)
Reference site and inclination	Kourou 5.2 deg.	Xichang 28.5 deg.	Baikonur 51.6 deg.	KSC 28.5 deg.	Baikonur 51.4 deg.	Odyssey Launch Platform 0 deg.	Kourou 5.2 deg.	CCAFS 28.5 deg.	CCAFS 28.5 deg.
Estimated launch price (2000 US$)	$165,000,000	$60,000,000	$85,000,000	$300,000,000	$42,500,000	$85,000,000	$112,500,000	$97,500,000	$55,000,000
Estimated LEO payload cost per lb (kg)	$4,162 ($9,167)	$2,003 ($4,412)	$1,953 ($4,302)	$4,729 ($10,416)	$1,404 ($3,093)	$2,431 ($5,354)	$5,007 ($11,029)	$5,136 ($11,314)	$4,854 ($10,692
Estimated GTO payload cost per lb (kg)	$11,004 ($24,265)	$5,233 ($11,538)	$8,326 ($18,359)	$23,060 ($50,847)	N/A	$7,343 ($16,190)	$10,651 ($23,486)	$11,890 ($26,217)	$13,857 ($30,556

Figure 4. Global Launch Vehicles Cost Per Pound [From 11]

With the demand never materializing, these expensive launch vehicles were incapable of supporting themselves in a commercial market, which left them on their governments' doorsteps requesting financial support [4]. The U.S. government pays to sustain the Atlas V and Delta IV launch vehicles through the EELV Launch Capability (ELC) contract, which supports the manpower and infrastructure. The ELC contract "enables a flexible contract structure in which the government aims to share an appropriate level of risk with the launch service providers, preserve the space launch industrial base, and stabilize the launch operations tempo" [12]. Europe's Arianespace receives its support for the Ariane 5 launch vehicles from the European Space Agency (ESA) and the French government.

2. Arianespace—Business Model and Strategy

Acting quickly and determined to reduce launch costs, Arianespace developed dual launch and multiple launch configurations for their Ariane 5 launch vehicles. These configurations allow for multiple satellites to be placed into orbit using only one launch

vehicle, thus reducing individual launch costs substantially. Their efforts at developing the dual launch capability started off slowly by testing and executing a few dual launch manifested missions until the risks could be mitigated and customer uncertainties were reduced. Today, they have seemed to perfect the dual launch capability. Airanespace's 2009 annual report brings these remarkable achievements to the forefront by reporting seven Ariane 5 launches in 2009; and of the seven launches five were dual-launch configured. In other words, five launch vehicles placed 10 large communication satellites into geostationary orbit at almost half the launch expense per satellite. What would cost approximately \$130–160 million U.S. dollars per satellite if launched individually is now a shared cost reducing the launch to \$65–80 million U.S. dollars. This strategy has paid huge dividends for Arianespace, which reported that they have placed more than half of all commercial satellites now in orbit [13].

Arianespace's efforts have made them the leader in commercial launch services, securing 11 of the 22 global satellite contracts for the 2009. This is half of the world's commercial launch service contacts and includes 9 of the 14 new satellites equating to 65% of the total market [13]. Currently, Arianespace is the only commercial launch system capable of launching dual payloads. One would think that such a configuration would only allow small satellites; however, the reality is that each satellite approaches the 10,000 lb mark and are delivered to a geosynchronous transfer orbit (GTO). On 14 November 2007, the Ariane 5 set a heavy lift record. It successfully launched two satellites, the Skynet 5B and the Star One C1, into a GTO. The two vehicles had a combined weight of 19,206 lbs, nearly the weight of a 38-foot school bus. The Arianespace 2007 Annual Report noted that it was responsible for 80% of the satellites placed in geostationary transfer orbit during 2007 making this a new record for the industry [14].

Since gaining experience in the dual launch configuration, Arianespace is now embarking on offering three distinct configurations for multiple payloads. The SYLDA 5 (SYstème de Lancement Double Ariane 5) is its workhorse and is capable of carrying the large full-sized satellites to orbit. The second, slightly smaller system is the SPELTRA

(Structure Porteuse Externe Lancement TRiple Ariane), which allows for lighter spacecraft or triple spacecraft configurations. The final system, which fulfills the smaller satellite requirements, is the ASAP 5 (Ariane Structure for Auxiliary Payload 5) adapter. This adapter is very similar in performance and design to the ESPA ring and is capable of carrying up to eight satellites considered to be mini and micro by definition. It can be mounted under the primary payload and carry up to eight 260 lb micro-satellites or can be mounted inside the Sylda structure and can carry up to four 660 lb mini-satellites.

The numbers reported in Arianespace's Annual Report show a company able to take a small market and generate profits with their high thrust large rocket. Its launch manifest is filled with customers and scientific missions ready for the future.

3. EELV—Application and Intent

The EELV concept has always followed the mindset that it is better to evolve a system versus drastically advancing a system. The success rate of evolved systems has continually demonstrated increased reliability when compared to launch vehicles that attempted to take drastic (repeated) steps or revolutionary redesigns. The typical first- and second-generation vehicles are plagued with launch failures and oversight defects. The best example of successful launch vehicle evolution in operational practice is the Soviet-built Soyuz rocket. This launch vehicle became operational in 1963 and has operated with a launch rate as high as 45 launches a year. By slowly evolving the system, The Russians have been able to create a highly successful launch vehicle with a 97% success rate, and is approaching 733 launches [15]. The Soyuz is also the preferred launch vehicle for Russia manned missions and has safely delivered astronauts and tourists to the International Space Station (ISS) [16]. In general, the evolved system is a safer way to ensure mission success and cost reduction. The EELV program is working diligently at making EELVs the future of reliable spacelift by mitigating risk and increasing standardization in design.

The U.S.-developed EELV concept began in the late 1990s when the U.S. launch industry embarked upon a joint venture with the Air Force. This effort authorized the Air

Force to give $500 million each to Lockheed Martin Co. and Boeing Corporation to evolve their current medium to heavy lift vehicles. The companies then added $500 million of their own capital to create launch vehicles capable of fulfilling the requirements for future demands. This large investment paid off with the creation of Lockheed Martin's Atlas V and Boeing's Delta IV launch vehicles.

When the EELV concept was created in the 1990s, it was built under the forecasted boon in the launch industry. With this growth never coming to fruition, the launch vehicles could not be supported under the actual launch manifests. Some drastic decisions needed to be made to ensure both the Atlas V and Delta IV would survive and maintain Assured Access to Space (AATS). AATS is the attempt to maintain two launch vehicles to limit the potential for a complete medium to heavy lift grounding if an issue occurs. If the United States must ground a fleet of vehicles from flying and there is only one fleet, then the United States loses space access and control. By maintaining two launch vehicles, the United States has a better chance at keeping one fleet of launch vehicles in operations while the issue is being resolved on the other.

On 1 December 2006, a decision was made that would forever shape the launch vehicle industry. The decision was to create a distinct and sole launch company called the United Launch Alliance (ULA), which would be capable of maintaining two launch vehicles and consolidating costs to attempt to make the industry profitable. This was a process in which the Lockheed Martin Co. and Boeing Co. combined "the assets of the two programs, including mission management and support, engineering, vehicle production, test and launch operations, and, most importantly, the people whose intellectual capital will enable the new venture [17]."

Now five years into the venture and a strict focus on mission assurance and launch vehicle development, what was once a sinking business is starting to show novel initiatives. The competitive mindset is becoming the answer to reducing launch vehicle costs and increasing success rates. Since their first operational use on 21 August 2002, the EELV vehicles maintain a record of 41 (25 Atlas V, 16 Delta IV) launches with a 100% mission success rate, and they continue to improve upon the systems, creating an

ever more robust and solid system. This continuous improvement is best noted at ULA's website, which shows their complete dedication to Atlas and Delta mission success along with their upcoming project of commercial human spaceflight and multi payload accommodations.

ULA is developing a new suite of options available for dual and multiple launch payloads. Their implementation of best practices is evident across the two systems with open communication, a sharing of ideas, and applying proven procedures across the board ensuring mission success is the #1 priority. Currently, the ESPA ring and other multiple payload options are being pursued in an attempt to satisfy customers and become more competitive in the global market. By examining and calculating the wasted margin in each mission, ULA can use the ESPA ring to deliver other assets to orbit, thus maximizing capabilities. Goodwin and Wegner [18] noted that U.S. government payloads are restricted to using U.S. launch vehicles. ESPA allows DoD small programs with typical small budgets the opportunity to launch on high-priced, high-reliable launch vehicles.

Even though the development of the large dual payload capability for the United States is still a few years away, the ESPA ring is available now and was operationally verified under the Space Test Program-1 (STP-1) mission launched aboard an Atlas V on 8 March 2007. This test program used the ESPA ring to launch four satellites into two different orbits verifying the capability exists to execute a multi-launch configuration successfully on any future mission with sufficient margin.

C. SPACE ACQUISITION REFORM

In 2001, a Space Commission was directed to assemble findings and recommendation for the approach in which the United States should handle space activities. *The Commission to Assess United States National Security Space Management and Organization* was created and headed by the Honorable Donald H. Rumsfeld. The commission noted, "the security and well being of the United States, its allies and friends depend on the nation's ability to operate in space [19]." This led to a set of areas in which

the commission should focus. Of the areas, a few directly pertain to the launch vehicles, propagation of space assets, and technology development, which ESPA can support. The report said the United States needed to "develop revolutionary methods of collecting intelligence from space to provide the President the information necessary for him to direct the nation's affairs, manage crises and resolve conflicts in a complex and changing international environment [19]." It also noted that a great need existed to "promote government and commercial investment in leading edge technologies to assure that the U.S. has the means to master operations in space and compete in international markets [19]." This focus is designed to "encourage the U.S. commercial space industry to field systems one generation ahead of international competitors [19]." By utilizing the excess margin on launch vehicle and creating a standard launch service, newly developed systems can perform in the operational environment much sooner by verifying the prototype designs. This acquisition approach is directly in line with the U.S. Government Accountability Office (GAO) recommendations [20].

The GAO, noted that space acquisition is a broken process in need of great changes to ensure successful management and mission execution to control program costs, schedules, and performances. "While DoD actions to date have been good, more changes to processes, policies, and support may be needed—along with sustained leadership and attention—to help ensure that these reforms can take hold, including addressing the diffuse leadership for space programs." [21] In a speech given by Senator Wayne Allard on 23 September 2005, he stated, "I strongly believe the continued mis-management of our space acquisition programs is a far greater threat to our space dominance than any external threat [22]." He went on to say, "over the last decade, we have done everything possible to sabotage our space supremacy [22]." His speech brought home the importance of changing the way space acquisition programs are being implemented and managed.

Another interesting note presented by Senator Allard was that space acquisition programs are reliant upon the technology development (or TRL) associated with the programs design. In other words, acquiring the system is at the mercy of the

subsystems being used based upon their TRL. Senator Allard continues to note that research and development does not belong in an acquisition program because the program becomes dependant on the technology being developed instead of managing the schedule [22].

General agreement exists that three major issues result in program failure or extreme overruns [23]. First, programs begin with poor requirement definitions at the onset of program development leading to unrealistic and over optimistic proposals during source selection. Second, the attempted implementation of new technologies, which resides in the infancy state of the Technology Readiness Level (TRL) spectrum mean the program is frequently delayed and will experience cost overruns. The third major cause of program meltdowns are the continued failure to use an evolutionary acquisition process properly coupled with spiral development, which is the standard for acquisition development but continues to be ignored in the desire for revolutionary approaches [23].

Discussed in the introduction, the SBIRS, AEHF, and NPOESS programs are three highly visibility programs that received Nunn-McCurdy breaches due to their system costs reaching a threshold greater than 25% over the approved contract value. These three programs have all experienced increased cost growth and schedule delays, and decreased system capabilities. When initially bid, the contracts were awarded for approximately $3 billion for the SBIRS program, $2.3 billion for the AEHF program and $6.8 billion for the NPOESS program [23]. After extensive cuts and schedule delays, the systems are forecasted to cost in excess of: $13 billion for the SBIRS program, $6.3 billion for the AEHF program, and $11.1 billion for the NPEOSS program, which was finally dissolved in February 2010. These examples are just a few that show how current programs continue to fall behind in cost, schedule, and performance. The lack of poor concept design, inaccurate proper TRL scoping, and improper evolutionary acquisition processes are causing these delays. Figure 5 shows a series of programs reviewed by the GAO showing SBIRS, AEHF, and NPOESS performance based on cost comparison and schedule growths. It is clear that a major and valid concern exists concerning the way in which programs are executed.

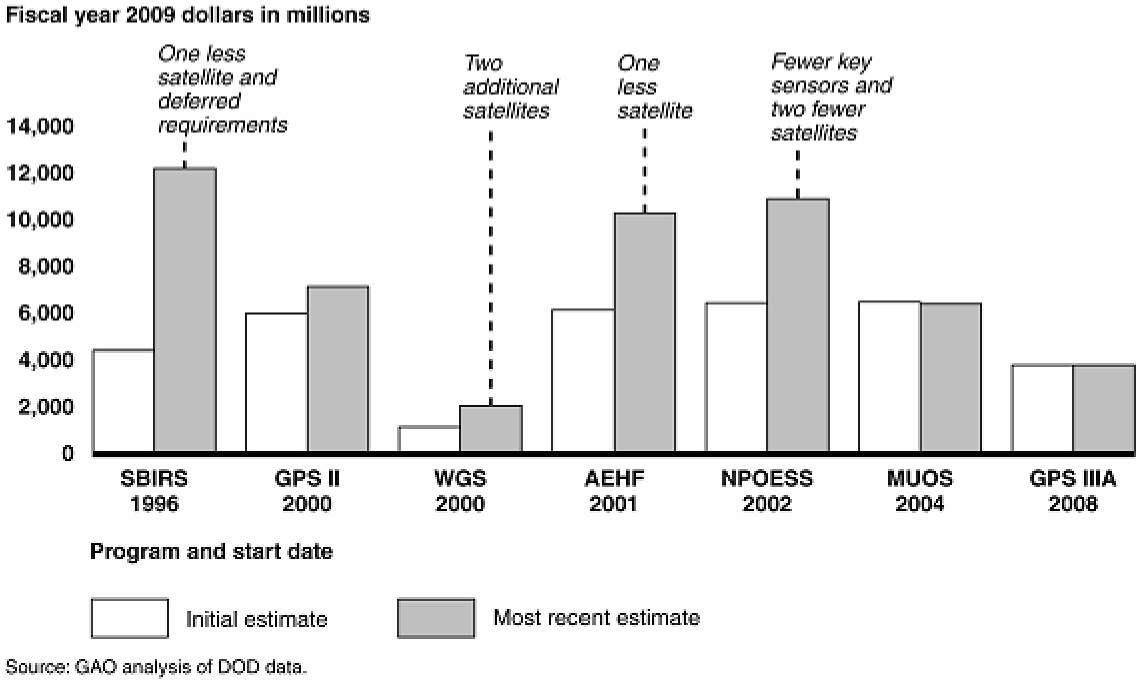


Figure 5. GAO Program Cost Growth [From 23]

The GAO report entitled *Space Acquisitions—The DoD Faces Substantial Challenges in Developing New Space Systems* reported four major areas that have caused substantial cost growth, schedule delays, and performance reductions when evaluating space programs. Two of the three areas directly relate to areas in which ESPA supported missions would assist with acquisition reform. The first area deals with program Authority To Proceed (ATP) beginning too early in the process. When most programs gain approved budgets, it is because the proposed technology is so advanced over the legacy systems that the benefits to national security or science missions seem to be worth the cost. The problems are that the proposed technology is not mature enough in its life cycle and it drives increased and schedule delays due to the program's requirement to develop the technology further through the latter parts of the TRLs. The GAO explains that programs typically must develop the technology since most R&D efforts do not

receive funding because they are labeled as lab work or experiments. A program labeled as an acquisition program receives more dollars and approvals over a program labeled R&D.

The second area in which ESPA can help improve acquisition reform is by breaking the customary approach of developing colossal systems capable of a multitude of missions and payloads over larger yet smaller constellations with less complexities. This approach is exacerbated due to the high cost of launch vehicles. If a mission is factoring in \$100–\$200M per launch vehicle, a more complex satellite is justified by recognizing the costs of reducing the number of required launches to populate a constellation.

Today's Congressional and DoD leadership are being very vocal about how the acquisition process is broken and that "requirements creep" will no longer be tolerated [24]. On 6 April 2009, Secretary of Defense Robert M. Gates announced key decisions for the 2010 defense budget. In his speech, he specifically discussed issues within the DoD procurement, acquisition, and contracting arenas. He noted that the defense acquisition process is going to be one of his three principal objectives of change. Effects are already being felt in the space acquisition process through his announcement that the Transformational Satellite Communication System (TSAT) program is being terminated. The termination of the \$26 billion program follows with his clear recognition that "adding layer upon layer of cost and complexity onto fewer platforms that take longer and longer to build must come to an end [24]." This quote confirms the days of creating complex mega-systems, with overstated requirements and underestimated costs, will become the exception rather than the norm. The new focus will be on the incremental development of small less complex systems.

Secretary Gates also continued to note that the new defense procurement process "requires an acquisition system that can perform with greater urgency and agility [24]." Creating systems with fewer "bells and whistles" and more responsiveness is beneficial to both program and national desires. By establishing a simplistic approach as the goal, the AF will be creating a new acquisition mindset, which offers "greater funding

flexibility and the ability to streamline our requirements and acquisition execution procedures [24]." This approach will be a completely different direction than the current approach in which program after program continues to not learn from others mistakes. This new approach will "guard against so-called "requirements creep," validate the maturity of technology at milestones, fund programs to independent cost estimates, and demand stricter contract terms and conditions [24]."

D. ESPA CONCEPT DEVELOPMENT

CSA Engineering developed the ESPA ring, under a Small Business Innovation Research (SBIR) program. Working with the Air Force Research Laboratory (AFRL) and Space and Missile Systems Center (SMC) Space Test Program (STP) detachment, it was able to communicate the requirements and operational inputs into an effective, simplistic, and affordable design. The structure allows one primary satellite and six secondary satellites to be launched on a single mission. The ESAP ring is a 1.5" thick cylinder made of 7075 aluminum with six main ports for secondary payload attachment. Additionally, access ports allow flexibility in gaining access to the inner chamber. Total dimensions of the ESPA are 24" tall and 62" in diameter. The impact to the spacecraft is 30 vertical inches due to the 24" high ESPA ring and the 6" high payload isolation system installed between the ESPA ring and the primary payload. This total height change is kept to a minimum, to reduce the overall impacts in loads analysis, acoustics, and hardware requirements typically requiring only longer connecting cables from the SV to LV through the ESPA ring. The thin aluminum design creates a stiff structure reducing the load factors to insure acoustic vibrations do not magnify through the structure. Strength was one main factor in designing the system. The single billet aluminum is machined to avoid the weakness associated with forging and increasing the overall stiffness enabling ESPA to carry a 15,000 lb primary payload and six 400 lb secondary payloads. The low stack height and stiff structure confirms the commitment to keeping the principal focus as being primary mission transparent.

ESPA can carry up to six APL with a total weight of 400 lbs and the design requirements require each satellite to fit within a 24"x24"x38" environment. As noted by

Goodwin and Wenger [18], the "most challenging part of the development of the ESPA ring has been to design a truly generic structure that will accommodate the desires of future spacecraft designers." This means a system must be created for satellites, which have not yet been designed or even conceived. Currently, the ESPA missions are designed to use the residual margin of capability from the launch vehicle remaining after calculating the requirements for the primary payload. This margin exists in all launches and can be the equivalent wasted margin of a medium class satellite. In [25] some cases, the margin (unused payload capability) can be as much as 3,628 kg (8,000 lb). Figure 6 is a notional bar chart forecasting future EELV missions and the predicted excess margin each mission will contain [26].

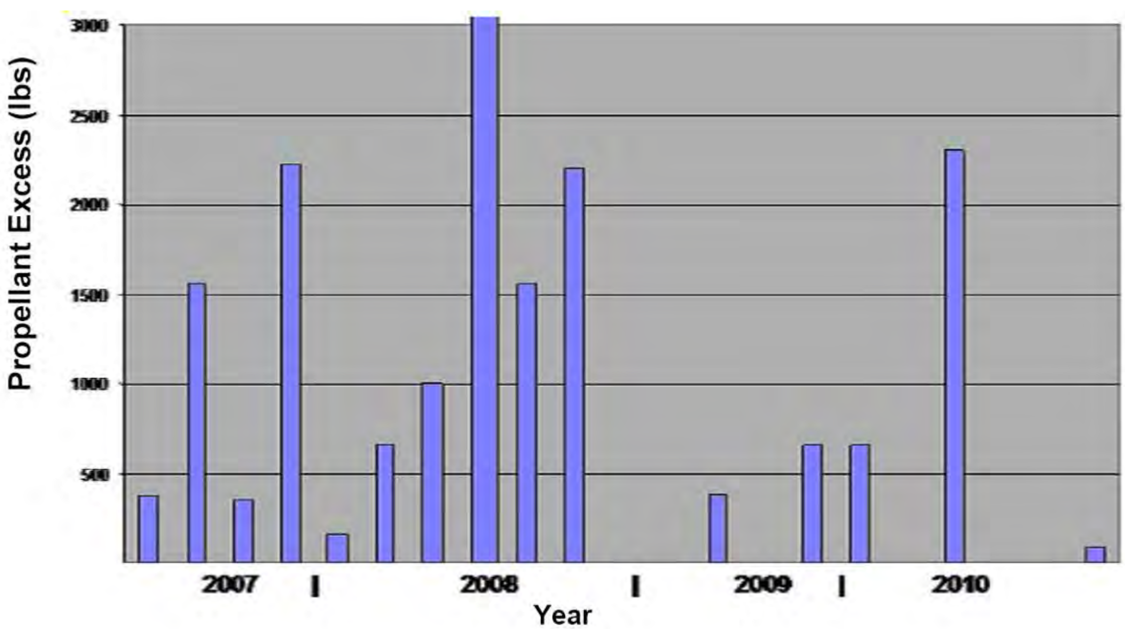


Figure 6. EELV Forecasted Launch Margin

A typical launch vehicle-satellite vehicle (LV-SV) integration process includes for some excess capacity that may remain unused during launch, which is called Margin. Many times this excess capacity is highly conservative and can be viewed as wasted capacity. The average medium-heavy launch vehicle's unused capacity ranges from 1,000 to 3,000 lbs per launch [25]. Some mission margins are >8,000 lbs [25]. The ESPA ring

is designed to make use of this margin and create a system upon which smaller satellites can piggyback at a greatly reduced cost. The ESPA ring's benefits are lengthy and have been proven to offer great incentives to research and development, scientific missions, and unique developmental concepts. The benefits are discussed in further detail in the paper, but the main focus involves explaining the apprehensions and integration challenges and offer solutions that will reduce these apprehensions.

The challenge for the ESPA ring is not in noting the available margin or even finding programs with a desire to operate on an ESPA ring, but instead the challenges rest with the integration complexities and "buy in" of the program managers on the primary missions. Adding complexity to a system, which is being monitored for its cost, schedule, and performance, drives program managers to a state of avoiding any new systems, which present increased complexity and potential delays. Working with the program manager and getting them involved in the steps will assist with the inherent desire to avoid additional activities. SV-LV integration is a complex process and involves many organizations with each party being concerned about its piece of the whole and its desire to ensure no additional risks are added to the mission. This idea of "keeping it simple" is desired since a basic principle of system engineering is to reduce the number of single point failures. By adding an ESPA ring and six other vehicles to the mission, the integration challenges will become more complicated and greater risks could be introduced. This thesis and chapter outlines ways in which Aerospace and the Space Test Program (STP) are regulating processes to reduce risk and increase standardization ensuring transparency in mission execution to the primary payload.

Another hurdle involves the program managers in charge of the missions. Program managers, by design, wish to reduce activities not absolutely required for mission execution. If an ESPA ring is used, then program managers must worry about changes in the acoustical environment, additional hardware, and a larger workforce. By standardizing processes and funding the additional testing involved, the impacts can be reduced, and thus, allow the program managers to have a better understanding of exactly what will be required and when the milestones will occur with the secondary payloads.

E. ESPA'S ABILITY FOR FULL SPECTRUM DOMINANCE

1. Operationally Responsive Space

Space operations typically rest in six primary mission areas, which drive the DoD and National Aeronautics and Space Administration (NASA) to pursue advancements in space capabilities. The mission areas are ISR, missile warning, environmental monitoring, communications, navigation, and exploration. These mission areas continue to be further honed bringing greater benefit to mankind. In an attempt to reduce cost and bring rapid responsive space capabilities to clearer focus, there is a push to develop a responsive space attitude. ORS is still in the early phases of development, understanding, and proper defining. This paragraph explains the route being pursued by the ORS office.

> ORS will provide an <u>affordable</u> capability to <u>promptly</u>, <u>accurately</u>, and <u>decisively</u> position and operate national and military assets in and through <u>space</u> and <u>near space</u>. The ORS vision is to provide rapid, tailorable space power focused at the operational and tactical level of war." Space Command views ORS as an <u>enabler</u> with four components: Responsive Satellites, Responsive Spacelift, Responsive Launch Ranges, Near Space systems. [27]

When read, the ORS vision seems to embrace a concept, such as the ESPA ring. ESPA can help exploit ORS by reducing costs and providing timely launch on demand capability. Having a more responsive and economical Science and Technology (S&T) program will allow the United States to remain ahead of rapidly evolving adversary space capabilities. This alleviates budget crunches by dividing the launch costs among multiple programs.

The GAO space acquisition [28] reported that the ORS "initiative encompasses several separate endeavors with a goal to provide short-term tactical capabilities, as well as identifying and implementing long-term technology and design solutions to reduce the cost and time of developing and delivering simpler satellites in greater numbers. ORS provides DoD with an opportunity to work outside the typical acquisition channels to more quickly and less expensively deliver these capabilities." ORS has a series of essential tasks and key operating principles. The ORS office defines two main areas for

preparing and executing rapid responsive capabilities [29]. The first is the need to develop end-to-end ORS enablers required to meet the nation's strategic need for highly responsive space capabilities. This includes satellite telemetry, tracking, command and control, satellite payload tasking and sensor data processing, exploitation and dissemination, responsive space CONOPS, and authorities necessary for achieving ORS objectives. The second is to execute rapid end-to-end capability efforts to meet urgent operational needs of joint force commanders. To empower the joint force commanders, systems will need to augment, reconstitute or implement new capability and complement the current fielded space capabilities.

2. Technology Readiness Level—Validation Through Fly-Offs

In a typical acquisition process for terrestrial-based products, a "fly-off" competition is exercised when developmental programs seem too complex or difficult to validate on paper alone. The idea is to have two or more competing contractors build working prototypes. These models are then tested and reviewed for feasibility, performance, and requirements adherence. What is accomplished is a validation of the technological readiness of the system. Developed by NASA in the 1980s, the TRL of a system is the "systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology [30]." By labeling the maturity of a particular technology, a better understanding of the effort required to bring the system into operational use is detailed. If a technology is too immature and still based on theories or only in a lab environment, it will have too many unknowns. If a technology is mature and has been validated in the operational environment for which it is intended, then that system proves its viability and utility in operations. As noted in the *Acquisition Manager's Guidebook*, "a key enabler for evolutionary acquisition and reduced cycle time is to have technology that is sufficiently mature to be fielded in a relatively short time. This requires having a method for measuring maturity, and a process for ensuring that technologies are sufficiently mature before being incorporated into systems that are being developed [31]."

However, in the space segment, most contracts are won with no physical proof that the capability is mature enough for development. The main reason is due to the difficulties in achieving orbit, the expensive cost of satellite development, and the limited number of satellites produced for each constellation. Most systems only produce three to six satellites and a fly-off would be excessively expensive. By having contracts awarded based on designs and proposals, many systems are still very immature. This unknown in performance has led many programs down the spiraling abyss of being over budget and brandished with the Nunn-McCurdy Breach stigma.

The ESPA ring can make fly-offs possible by testing proposed payloads. In many situations, technology risks to TRLs only rest in a few components on the satellite. Typically, the bus's thrusters, heating systems, and attitude controls are already widely used in satellites. The real risk is with a few of the payload's sensor components or data links. These areas can be tested in the operational environment through small payloads aboard an ESPA mission. By making more unknowns known, the government would have better control in the acquisition process and could award contracts with less risk.

> The key to transitioning technology—whether developed by industry or government—is the availability of sufficient funds to mature technology through later TRLs. Great ideas in the laboratory many times do not translate easily into workable DoD systems. Funds to mature and test these ideas are needed; however, the budget cycle for most programs requires as much as two years of planning before funds are available. Therefore, the technology provider and the PM must agree early and plan to prevent funding lapses during development. [31]

Figure 7 is from the *Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment* [31]. The figure defines each of the nine TRLs. What is important to observe is that a TRL jump from six to seven is the transition from science and technology typically performed in a lab environment to an operational environment test. If the technology is demonstrated in an operational test, it is considered to be mature enough for acquisition community to develop into systems with acceptable risk.

TRL	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples are paper studies of a technology's basic properties.
2. Technology concept or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and proof or detailed analysis might not be available to support the assumptions. Examples are limited to analytical studies.
3. Analytical and experimental critical function or characteristic proof of concept.	Research and development is initiated, including analytical and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Validation of component or prototype in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5. Validation of component or prototype in relevant environment.	Fidelity of prototype technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System or subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test-bed aircraft.
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of system development. Examples include developmental tests and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proved through successful mission operations.	Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: *Interim Defense Acquisition Guidebook*, October 2002.

Figure 7. TRL Description (From: AMGB, 2003 [From 31])

After a technology leaves the scientific area, it is typically developed to deliver some type of capability for a higher level system. An example of this type of capability is a new camera system for a micro-satellite. If a capability is crucial for an upcoming satellite system, the government program manager will likely assign a performance metric to track. This type of performance metric is called a Key Performance Parameter (KPP). KPP are the required capabilities that a system must operate within and deliver for the program. Being able to test this capability and measure the performance (the KPP) in a real operational environment would be of significant benefit to both the government and the capability developer. This testing allows the government and contractor to have a common goal to achieve for mission performance. By taking the new technology and testing it in the operational environment, the feasibility and concept is proven, which greatly reduces the unknowns in development. Learning from mistakes, it is possible to start to see greater accountability in verifying higher TRL's in each system prior to the beginning the acquisition life cycle. In the *Hearing on the Fiscal Year*

2008 Budget Request and Status of Space Activities, it was noted that "historically, programs perform better when they have clear, stable requirements, technology at the appropriate level of maturity, and high-confidence cost estimates early in the acquisition process [32]."

3. Adherence to GAO Recommendations and Acquisition Reform

The GAO is known as "the investigative arm of Congress" and "the congressional watchdog." "GAO supports Congress in meeting its constitutional responsibilities and helps improve the performance and accountability of the federal government for the benefit of the American people" [33]. The GAO is responsible for evaluating programs and grading them on their performance in regards to cost, schedule, and budget management. Due to the recent abundance of Nunn-McCurdy breaches, the GAO's role is becoming more prominent.

Following GAO's review of the space acquisition process and following programs with success and failures, a list of steps has been compiled to help with the selection of new contracts, and once a contract has been awarded, the monitoring of the contract. Figure 8 outlines the steps needed for successful execution of space acquisition programs [34]. The ESPA system assists in fulfilling these by bridging the gap between the laboratory and the environmental operation and test. The bolded bullets show where the ESPA system can offer a direct benefit to programs. As the GAO recommends, a program should not begin until the TRL of a system moves from Level 6 to Level 7. This transfer allows for the prototypes to be tested in the operational environment. What happens when a program is initiated when the technology is already at a Level 7? There are two polar opposite and conflicting answers. First, the program has a much higher chance of being on time, on budget, and offers substantial leaps in improvement over the predecessor system. Second, the program is frequently viewed as simple and obsolete in the aerospace industry since few leaps and challenges need to be resolved during the research and development phase. This commercial off-the-shelf (COTS) approach does

not bring about the award winning challenges sought after through revolutionary approaches, but it is beginning to be viewed as the recommended way to initiate a program.

Before undertaking new programs
• Prioritize investments so that projects can be fully funded and it is clear where projects stand in relation to the overall portfolio.
• Follow an evolutionary path toward meeting mission needs rather than attempting to satisfy all needs in a single step.
• Match requirements to resources—that is, time, money, technology, and people—before undertaking a new development effort.
• Research and define requirements before programs are started and limit changes after they are started.
• Ensure that cost estimates are complete, accurate, and updated regularly.
• Commit to fully fund projects before they begin.
• Ensure that critical technologies are proven to work as intended before programs are started.
• Assign more ambitious technology development efforts to research departments until they are ready to be added to future generations (increments) of a product.
• Use systems engineering to close gaps between resources and requirements before launching the development process.
During program development
• Use quantifiable data and demonstrable knowledge to make go/no-go decisions, covering critical facets of the program such as cost, schedule, technology readiness, design readiness, production readiness, and relationships with suppliers.
• Do not allow development to proceed until certain thresholds are met—for example, a high proportion of engineering drawings completed or production processes under statistical control.
• Empower program managers to make decisions on the direction of the program and to resolve problems and implement solutions.
• Hold program managers accountable for their choices.
• Require program managers to stay with a project to its end.
• Hold suppliers accountable to deliver high-quality parts for their products through such activities as regular supplier audits and performance evaluations of quality and delivery, among other things.
• Encourage program managers to share bad news, and encourage collaboration and communication.

Figure 8. Successful Execution of Space Acquisition Programs [From 34]

The Wideband Global SATCOM (WGS) is a perfect example of a program with a mature TRL at inception. In the beginning, the WGS system was called the Wideband Gapfiller System (WGS) and was intended to be a quick acquisition system to fill the

foreseen gap left from Defense Satellite Communications System (DSCS) satellites. The gapfiller connotation has been used on many programs to show that the system is not intended to be the follow-on or replacement system, but just a simple system to augment the current constellation, which has been forecasted to operate below mission requirements due to either a loss of a satellite or degradation of capabilities. Once the DSCS follow-on (Advanced Wideband System) was determined to be too complex with a price tag too expensive for Congress, "Gapfiller" in WGS was replaced with something more enduring like "Global." Now the constellation is known as Wideband Global SATCOM (WGS) and the performance is nothing shy of revolutionary when compared to the DSCS system. Each satellite can support data transmission rates ranging from 2.1 Gbps to more than 3.6 Gbps. By comparison, a DSCS III satellite will support up to 0.25 Gbps [35]. Due to the termination of the Advanced Wideband System, the DoD has now ordered six total WGS systems and predicts a long future for the constellation.

The greatest lesson learned from the WGS program is that a system built from evolutionary processes, as opposed to revolutionary, will typically come very close to their milestones in cost, schedule, and performance. The WGS system was one success story that arrived at the right time and within budget but brought with it 10 times greater capability than the previous DSCS system. Currently, the WGS system is one of the few space programs to wear a badge of honor in the acquisition realm.

F. SUMMARY

The complexity in forecasting and developing new systems to meet the demands of the warfighter continues to become more difficult and creates programs with significant uncertainties. As noted in this chapter, many space programs have doubled their budget, doubled their time, reduced their quantity and reduced their systems requirements. This moving target approach needs something to give the acquisition manager better influence in determining the true cost, schedule, and capabilities being requested. The ESPA ring provides prototypes as a means to advance TRL from the laboratory into the operational environment.

III. ESPA'S MISSIONS AND ROLES

A. INTRODUCTION

With a goal of reducing the number of single point failures on launch vehicles, the aerospace industry is apprehensive about changing current processes and pursuing new endeavors. This mindset drives building redundancy in the system and removes anything not absolutely required. First, this approach is great for mission risk reduction, but at a severe cost to scientific research and potentially significant unused margin. Second is the missed opportunity for the industry leaders to pass their experience and knowledge on to auxiliary payload's developmental teams, specifically experience with reducing risks and properly applying technological advances under the most controlled processes. The APL providers must leverage the experience of the government, industry and aerospace personnel to ensure their program begins with a solid base of requirements.

Many potential auxiliary payloads' program managers might be under the impression that they fully understand the launch process, but truly, they are unaware of the extreme complexities required to enable launch success. The 14th AF has taken the first step by developing the processes and milestones used to determine EELV assigned launch dates. This board, known as the Current Launch Schedule Review Board (CLSRB) assigns "slots" to all contracted EELV missions allowing adequate time to plan for specific launch dates at the earliest opportunity. Studying the successful STP-1 mission, LCROSS mission, and the future DSX mission, program managers will gain a thorough understanding of the difficulties involved in designing, integrating, and executing a multi payload mission.

B. EELV SECONDARY PAYLOAD ADAPTER (ESPA) MISSIONS

1. Space Test Program-1

On 8 March 2007, the first ESPA-ring on an Atlas V was successfully launched from Cape Canaveral Air Station. STP and the Defense Advanced Research Projects Agency (DARPA) funded this mission to give smaller payloads and scientific

experiments the opportunity to perform their operational missions. The mission was named the Space Test Program-1 (STP-1) and launched aboard an Atlas V EELV. The Centaur upper stage performed multiple orbital maneuvers to deliver the payloads into two different orbits. With the upper stage and ESPA ring (Figure 9) performing flawlessly, each payload was able to bring valuable research and on orbit data to future programs. This single launch was responsible for validating many scientific experiments, which typically require years of waiting for individual rides. The missions are explained in detail solidifying the unique benefits ESPA rings can offer typical low cost experiments. Figure 10 shows the integration of the secondary payloads onto the ESPA Ring.

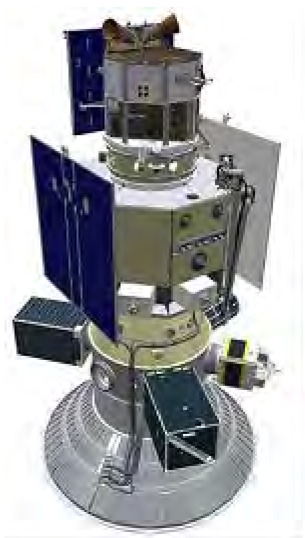


Figure 9. STP-1

Figure 10. STP-1 SV Integration

a. STP-1 Primary Mission

Orbital Express is a DARPA-funded project, which "will validate the technical feasibility of robotic, autonomous on-orbit refueling and reconfiguration of satellites during a three-month mission" [36]. This program deployed two satellites, Next Generation Serviceable Satellite (NextSat), and the Autonomous Space Transport Operations (ASTRO). Together, the two systems docked and transferred fuel robotically,

proving the feasibility to repair or upgrade existing satellites. A lesson learned from the NextSat and ASTRO docking mission was the need for common connecting joints. Much like the common Universal Serial Bus (USB) connection on today's computers, handhelds, and MP3 players; a common docking connection is needed for spacecrafts to perform on-orbit refueling and parts replacements. In a space reform discussion, Lee [37] recommends using standardized common components approach and plug-and-play architecture. This modular structure allows for the creation of satellites similar to the highly successful structure of personal computers. Making a bus and payload system capable of upgrades, a program can continue to evolve with technology readiness levels. The ability of the long acquisition cycle (sometimes 10 years prior to the first SV launch) to upgrade subsystems will help the program stay ahead of the technology curve and reduce the possibility that the satellite is outdated before it even launches. The data Orbital Express will provide for validation of on orbit fueling and repair will allow this plug-and-play approach to be feasible for future systems and make upgrades possible during a program's acquisition life cycle.

b. STP-1 Auxiliary Missions

STPSat-1 is a Space Test Program satellite designed with two primary missions and one secondary mission. Together, the data received is answering scientific questions about the Earth's atmosphere and proves Micro-Electro-Mechanical Systems (MEMS) technology. The Spatial Heterodyne Imager for Mesospheric Radicals (SHIMMER) is a high resolution ultraviolet spectrometer, which is the first satellite to use the spatial heterodyne spectroscopy (SHS) technique that "significantly reduces the instrument's size and weight while retaining the spectral resolution and exceeding the sensitivity of comparable conventional instrumentation [38]." The second payload is the Scintillation and Tomography Receiver in Space (CITRIS). This experiment is presenting a global map of ionospheric densities and irregularities. MEMS PicoSat Inspector (MEPSI) deployed from STPSat1 and performed maneuvers and proximity operations. "It is the first microsatellite built to specifically exploit the new ESPA multi-mission launch capability [39]."

CFESat, or Cibola Flight Experiment Satellite, was developed by Los Alamos National Laboratory and is designed to detect and survey VHF and UHF signals. This mission is assisting with reducing and correcting single event upsets that may cause most computer systems to malfunction. CFESat will also prove space capable field-programmable gate arrays, which until now, have only been used terrestrially [40].

FalconSat-3 gave Air Force Academy students' hands on experience into designing, developing, and deploying an operational satellite. This three-axis stabilized system carried five payloads and "requires ± one degree attitude determination within two standard deviations and ± five degree attitude control within one standard deviation of ram direction [41]." These tight tolerances make this micro satellite a highly capable research vessel and can bring valuable data for future missions.

MidSTAR-1 was built by the U.S. Naval Academy to test the application of a sensor that can detect more than 15 different chemicals for safety and identification from something as small as a postage stamp. The satellite is also equipped with a variable emissivity film. "Used on a spacecraft, the film can reduce launch weight, make future thermal design easier, reduce power consumption, and allow more accurate control of the spacecraft's inside temperature [42].

c. STP-1 Firsts

The STP-1 mission challenged the aerospace industry towards innovative thinking. This challenge came through performing many unique integration challenges and upper stage maneuvers. The first involved making this the inaugural launch of an Air Force mission aboard an Atlas V launch vehicle. Not only was this the first Air Force EELV mission, but it was also the first time an ESPA Ring was used on any mission. The Centaur upper stage was also put to test by deploying seven unique spacecrafts (nine total experiments) into dual-orbits with different inclinations. This required the Centaur upper stage to perform three main engine ignitions, which was the first time this was done on an operational mission.

2. NASA's Lunar CRater and Observation and Sensing Satellite (LCROSS) and Lunar Reconnaissance Orbiter (LRO) Mission

Pursuing the vision of placing a man on Mars, NASA is returning to the moon as a layover station. To find a suitable landing site and search for sufficient quantities of hydrogen for human survival in the form of water and for producing rocket fuel on the moon, the LRO and LCROSS missions were designed to work together in a joint effort to map and detect soil content on the moon. LRO is the primary mission with the LCROSS mission being made possible by imaginative thinking and utilizing unused launch vehicle margin. This unused margin provided scientists with the opportunity to develop another mission and achieve greater benefits from a single launch. After screening a series of potential missions, the LCROSS mission was chosen. This mission deployed the LRO satellite and then prepared itself to send the Atlas V Centaur upper stage on a path to impact the moon. The kinetic energy caused a crater approximately 20–30 meters in diameter with a spectroscopic data reporting approximately 25 gallons of water released from the surface of the moon [43].

Capitalizing from the use of a single Atlas V EELV, NASA used an ESPA ring to create a complex multi-exploration mission. The ESPA ring acted as the adapter for the LRO vehicle and was the primary structure for the LCROSS spacecraft. Using the ESPA ring, the LCROSS structure allowed each attachment location to become a specific subsystem and reduced the technical complexity.

Since the LRO mission was paying for the booster, the LCROSS mission received a ride for almost free by using the space margin available, which allowed LCROSS to be "built, integrated, and tested by Northrop Grumman in just 26 months for the NASA Ames Research Center on a $56 million contract [44].

On 18 June 2009, the LCROSS and LRO missions were launched from Cape Canaveral, FL. After LCROSS separated from the LRO spacecraft, it continued to be connected to the Centaur upper stage. The orbital path took the vehicle from a lunar pass, and then it returned to begin orbiting the Earth. This process took nearly 113 days, and

the vehicle traveled nearly 5.6 million miles. Once it was time for mission execution, the LCROSS vehicle released the Centaur upper stage (Figure 11), and it impacted the moon on 9 October 2009 (Figure 12).

Figure 11. LCROSS Centaur Separation

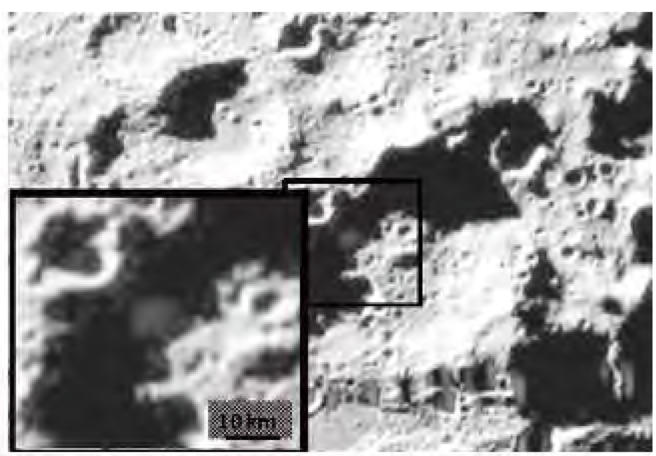


Figure 12. LCROSS Image of Moon Impact

LCROSS took data readings and observations of the impact in multiple spectrums. For approximately four minutes, the system collected data, and then it sent

itself on a path to impact the moon, gaining even more useful data. LRO continues to orbit the moon collecting data. "We are ecstatic," said Anthony Colaprete, LCROSS project scientist and principal investigator at NASA's Ames Research Center in Moffett Field, CA. "Multiple lines of evidence show water was present in both the high angle vapor plume and the eject curtain created by the LCROSS Centaur impact. The concentration and distribution of water and other substances requires further analysis, but it is safe to say Cabeus holds water" [45].

The success of the STP-1 and LCROSS missions is gaining support throughout the Aerospace community and encouraging more programs to continue researching innovative ways an ESPA ring can benefit future projects. An example of the support and innovation is the Demonstration and Science Experiments (DSX) which is detailed in the following section.

3. Upcoming ESPA Mission

a. DSX

The Air Force Research Laboratory (AFRL) is developing the DSX satellite to fly secondary aboard an ESPA ring equipped DMSP Flight-19 mission. The mission is scheduled for an October 2012 launch on an Atlas V launch vehicle from Vandenberg Air Force Base (VAFB). This is another great opportunity for the Space Development and Test Directorate (SDTD) office to prove the ESPA ring's benefits in an operational environment. The DMSP launch presents an ideal orbit for the mission requirements of DSX and plenty of residual margins exists to carry the DSX SV along for the ride. The DSX payload consists of 13 individual payloads, which are combined together to focus on three major areas of space physics and the space environment through tests of the Wave Particle Interaction Experiment, Space Weather Experiment, and Space Environmental Effects. Figure 13 shows the DSX satellite attached to an ESPA ring at the AFRL Space Vehicle Directorate.

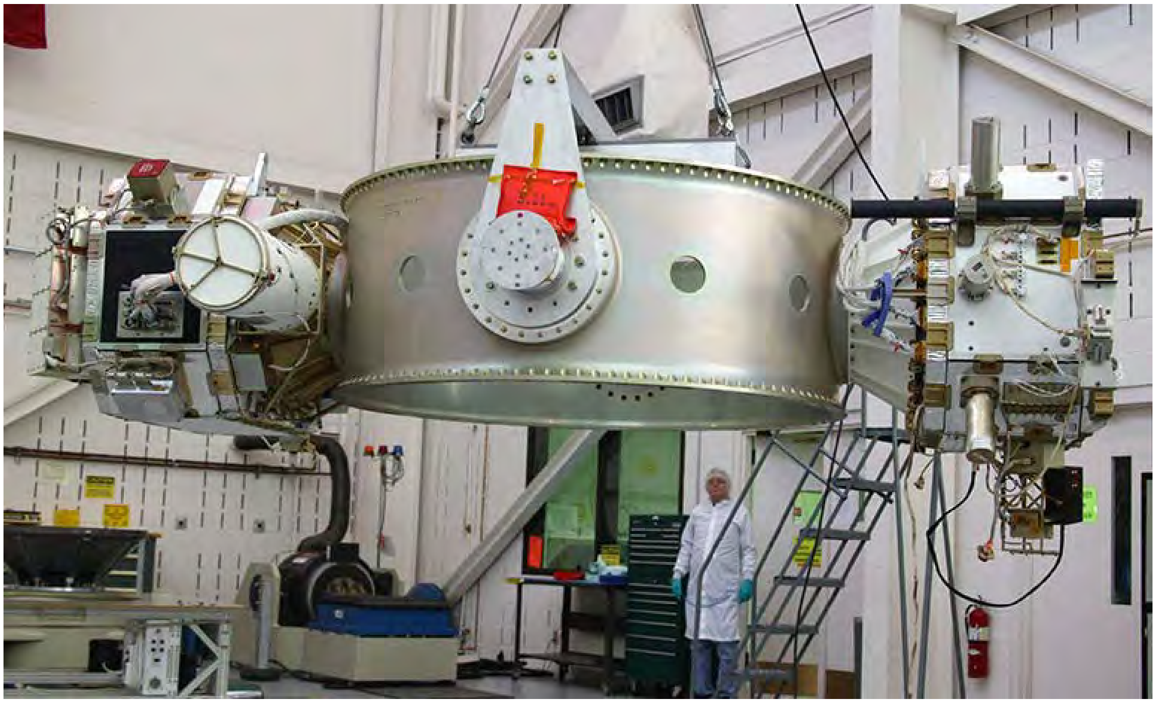


Figure 13. DSX During Testing at AFRL Space Vehicles Directorate

b. Primary Objectives of DSX

The primary objectives of DSX as reported by Scherbarth [46] are listed below:

- The DSX system shall resolve critical feasibility issues for VLF Wave-Particle Interactions to include determination of VLF antenna injection efficiency from ground and space-based transmitters, characterization of the global distribution of natural and man-made VLF waves in the inner magnetosphere, and the detection of perturbations of particle populations due to injected VLF.
- DSX shall measure and map the distributions of energetic protons, electrons, and low energy plasma in the inner magnetosphere to improve models for spacecraft design and operations.
- DSX shall operate a minimum of one year in the space environment.
- DSX will conduct an Adaptive Controls Experiment (ACE) to validate critical attitude control technologies that target flexible structural modes, adapt to changes in on-orbit dynamics and extend attitude control bandwidth

Another area in which the ESPA ring could offer benefits to the DMSP program would be as a relay for DMSP satellites with failed tape recorders. “These spacecraft are still taking valuable data in real-time and are able to downlink the data for field terminal users. However, there is no way for the satellites to relay their data when they are out of site of a ground terminal [47].” This would be a perfect opportunity for ESPA to carry small relay satellites to fly within the orbital parameters of DMSP satellites recording and relaying the data upon command.

4. ESPA Missions Summary

It is remarkable to see these two unique missions, STP-1 and LCROSS, offer many benefits to scientific and operational activities. These missions brought about great progress in advancing scientific knowledge and TRL. Together, these two missions brought about 17 scientific experiments to advance knowledge and understanding of future mission designs. Other areas noted by Chavez, Barrera, and Kanter [47] ESPA systems could analyze GPS environments and add improvements to follow-on systems. Future programs can use the ESPA ring as a complete constellation dissemination system delivering up to 18–24 satellites through one launch, which would be accomplished by stacking 3–4 ESPA rings within one payload fairing and maintaining the designed six-satellite configuration per ESPA ring. Large constellations, similar to the 66-satellite Iridium constellation, could be populated with three or four EELV launches. The future holds extensive options for mission integration and advancements of the state of U.S. technology.

C. MISSION INTEGRATION

By adhering to the rules laid forth in the ESPA RUG, the auxiliary satellite developers will be able to focus on implementing the proven requirements to achieve the desired mission success. Conforming to these rules is vital to ensure the ESPA initiative survives. The only way to get and keep the ESPA ring in operational status is through proven performance and minimizing interference with the primary mission. The integration challenges for the program manager are similar to an orchestra conductor

trying to keep the instrument ensemble on tempo. This manager needs to have a clear understanding of what all parties offer and their desires for success. By working to bring all parties together in a formal controlled fashion the program manager can achieve mission success. There are four critical activities that have to be accomplished by the program manager. The four activities are: taking appropriate risks, promoting the use of ESPA Policy, establishing quality standards, and controlling the integration process.

1. Fear of Risk Can Mean Lost Opportunities

Apprehension for the ESPA ring is driven by the industries risk reduction mindset and resistance to change. Program managers are focused on the primary payload and do not want to add additional complexities to their mission. The ESPA ring adds a new layer of integration to the launch but brings benefits, which are explained in the next chapter. Higher level leaders in the acquisition chain of command, who know the benefits that ESPA ring offers, must promote the program. Also, a system must be in place to ensure secondary payloads adhere to all standards through a consistent format detailing all requirements.

2. ESPA Policy

Forceful leadership support occurred on 13 February 2008 when the Secretary of the Air Force signed a memorandum on the subject of EELV Secondary Payload Adapter (ESPA) Policy. This memorandum was the essential step needed for the progress of the ESPA ring's utilization in missions with sufficient margin. Three major points can be gleaned from the memorandum. The first is the realization that EELV missions do have sufficient excess weight margins and this excess weight should be used to maximize the ESPA. "As such, it is my policy to make ESPA-hosted satellite launches a routine operation starting NLT FY12 [48]." Second, the development of an ESPA utilization plan and implementation guidance is required by the FY10 POM (Program Objective Memorandum). "AFSPC should also continue near-term efforts to make the ESPA available as a low-cost, highly reliable, standardized service for small payloads when technically feasible and consistent with overall mission assurance [48]." Third, ESPA is

an affordable system for scientific, research, development and ORS systems, and provides a lower cost method to place their payloads in orbit. With the additional leadership scrutiny, the APL provider must present a quality product with valuable research and a solid mission design. “This policy is an important milestone in our efforts to provide routine and affordable access to space for scientific, research, development, and Operationally Responsive Space (ORS) missions [48].”

3. Quality Is Mandatory

The APL provider must follow strict adherence and unique requirements. In other words, the success of the ESPA depends on the earnest efforts of the secondary payload provider. The secondary payload provide must ensure the development of quality spacecrafts that follow the exacting guidance found in the ESPA RUG, which will promote mission success for all parties. This approach is not a novel idea but one in which new entrants, or small developers, need to learn from the leaders in the industry. Government program offices need to provide the leadership and financial planning to ensure the authority to perform APL implementation is exercised. APL providers must minimize risk for the primary payload by following a documented approval process contained in two key documents. The first document, which gives build requirements for APLs, is the ESPA RUG. The second is the Standard APL-ESPA-LV ICD (Interface Control Document) that takes the current Satellite Vehicle (SV) to LV ICD and adds in the APL/ESPA requirements for the satellites and launch vehicle. SMC and STP are creating these documents to help standardize the integration efforts and reduce system risks.

4. Vehicle Integration

With AFSPC taking the lead on the ESPA program and following the direction to offer a low cost ride using excess margin, the majority of the required costs are covered by the primary payload and the support costs by SMC’s Launch and Range Systems Directorate (LRSD). This leaves the integration costs as the only real expense for the secondary programs. In *Operational Satellite Concepts for ESPA Rideshare* [47], this

generous approach is restated by noting that integration and processing are the only costs incurred by the secondary payload provider, and not launch vehicle hardware and operations. This greatly reduces the cost because it eliminates the need to procure individual launch vehicles for each secondary payload.

Utilizing large vehicles to carry additional small payloads is an excellent way to use the excess margin wasted on a majority of the launches. If the ESPA system is embraced, it will allow mission schedulers to view launch manifests years into the future and schedule slots for secondary payload configured missions. With this known launch tempo, secondary payloads can begin building their satellites to the ESPA specifications early in the development process and decrease the combined (primary and secondary) mission integration time drastically. This method would also create a pool of "ESPA ready" satellites ready for launch. By having a pool of missions to choose from, the integration can begin at L-24 months and progress towards L-12, when the potential secondary payloads are screened based on integration readiness. This early preparation and integration activity will create a more responsive system achieving a timely, near ORS behavior.

D. ROLES AND RESPONSIBILITIES

The launch of an ESPA mission consists of four main participants, who collectively require effective communication and candid observations to ensure compliance and mission success. The four main players are the STP, APL, LRSD, and ULA. Encircling those players stands an outside observer known as the Independent Readiness Review Team (IRRT), which is responsible for providing an independent assessment of the data and mission success.

1. DoD Space Test Program (STP)

STP is a subordinate under the Space Development and Test Directorate (SDTD) based at Kirtland AFB, New Mexico. STP "develops, tests and evaluates Air Force space systems, executes advanced space development and demonstration projects, and rapidly transitions capabilities to the warfighter [49]." The STP office is responsible for the receiving and coordination of APL requests. When a program needs further clarification about launching aboard an ESPA designed EELV, it coordinates requests for information through the STP office. Once a program desires to pursue a flight request, the STP office verifies its mission's needs with upcoming ESPA mission configured flights. Next, potential candidates are released to the program to determine which mission works best. Once STP notifies the APL of which mission it is assigned, the APL receives the ESPA directives and mission kit, which must be followed to ensure compliance with established procedures. STP also coordinates the mission with the other parties to ensure agreement and inform of future activities.

2. Auxiliary Payload (APL) Provider

The APL provider is responsible for preparing and providing all required documents and testing to ensure a safe flight and noninterference with the primary payload. The work involved in designing the spacecraft must be built around the requirements set forth in the ESPA RUG, which must follow the APL manifest and mission assurance and risk reduction/mitigation plan. The APL must provide a mass simulator at the start of the mission. This simulator is required to ensure a backup plan exists to fill the void if the secondary payload cannot make flight.

3. Launch and Range Systems Directorate (LRSD)

LRSD at Los Angeles Air Force Base is responsible for monitoring and maintaining a full understanding of all upcoming launches. It maintains the database, which contains specifications on future launches and available margin. STP uses this database to determine suitable missions with sufficient margin for future ESPA activities.

LRSD is the primary point of contact for funding and contract issues. If an APL indicates a mission has unique requirements, the LRSD ensures compatibility with the launch vehicles. LRSD also handles the launch vehicle contract and booster and ground support equipment expenses of the APL.

4. United Launch Alliance (ULA)

United Launch Alliance focuses on the direct connection and adapters for the ESPA and Primary payload. They acquire the hardware and kits required for ESPA missions. It is also responsible for the entire integration process. As previously mentioned, ULA is working new initiatives to offer more payload configurations, allowing multiple variations of weight and sizes of satellites to fly aboard the Atlas V and Delta IV launch vehicles.

5. Independent Readiness Review Team (IRRT)

"The purpose of the Independent Readiness Review Team (IRRT) is to minimize the risk involved in a forthcoming launch by having an independent group of experts assess the readiness for launch of the flight hardware and the appropriate supporting elements [50]."

Figure 14 shows how the primary payload and the APL teams work with the ESPA mission planners. The figure gives a breakdown of their primary responsibilities and shows how IRRT is separate and acts as an outside observer with no vested interests.

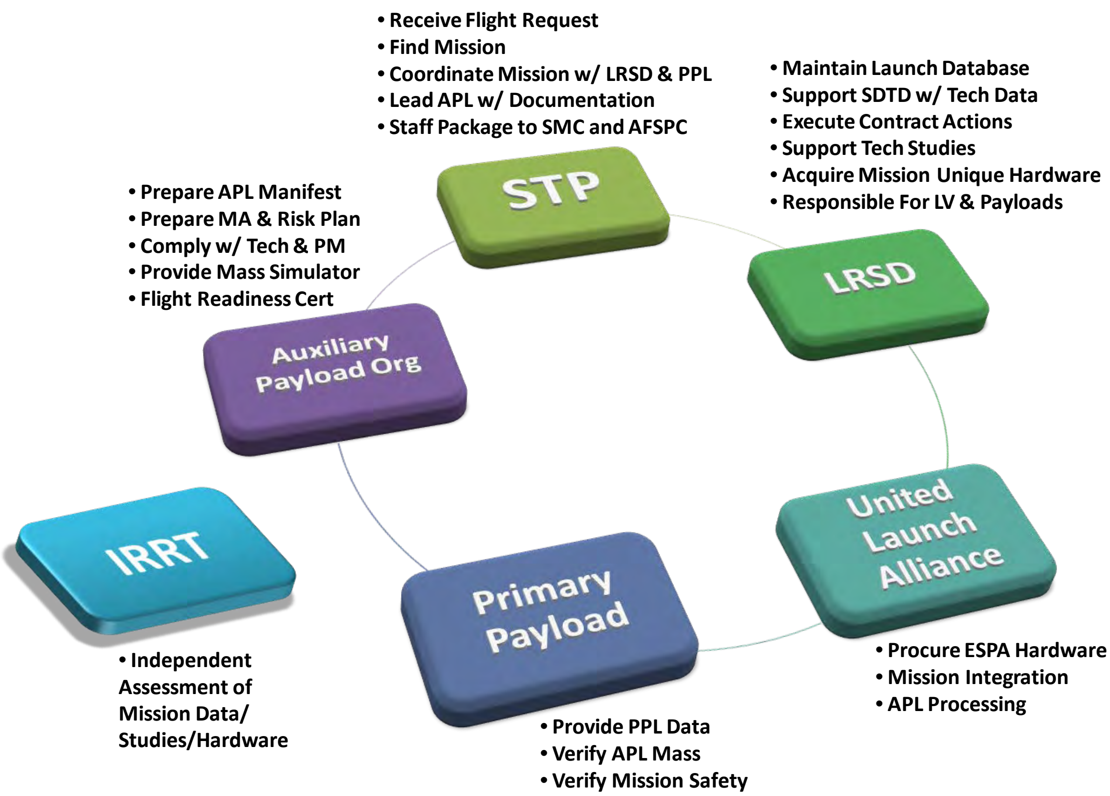


Figure 14. Snapshot of the Organizations Involved and their Requirements

E. SUMMARY

This chapter reviewed the STP-1 mission, the LCROSS mission and the future DSX mission. Each of the mission's challenges, integration issues, and benefits brought about by introducing an ESPA system into a launch were discussed. It concluded with a detailed description of the players with ESPA and described the documents for APL adherence. This chapter provided an overview of the different parts of the system that facilitate ESPA missions. With the leadership guidance, specification documents and the mission and roles identified, creation of a standardized service is possible, ensuring available rides for satellites built within required specifications. With this gained appreciation for the ESPA system, the Cal Poly CubeSat program will be discussed in the next chapter to show how a smaller scale "ESPA" system has proved successful.

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IV. STANDARDIZING FOR SUCCESS

A. INTRODUCTION

Capitalizing on experiences from others is a standard engineering practice due to the rapid ability to implement the countless hours of knowledge and lessons learned from previous endeavors. Learning from experts and programs, which have great commonality, allows secondary payload developers to achieve milestones with more efficiency and ease. The California Polytechnic University and Stanford University developed the CubeSat program as a low-cost research capability for space access. Their concept is simple and has been embraced globally by universities and commercial and government organizations. The process revolves around the idea of multi-satellite development, standardization, and deployment activities, which resemble the ESPA standardization concept. Their simple, low-cost, no-frills approach has created a wave of very successful programs, which fit in a 10 cm cubed spacecraft form factor with a mass up to 1.33 kg. CubeSats have been successful due to the detailed specifications, which when followed from the onset of a program, make the integration and deployment very streamlined. Toorian, Blundell, Puig-Suari, and Twiggs [51] described three major CubeSat design specifications, which keep the CubeSats standardized through general specifications, P-Pod driven specifications, and safety specifications.

B. CUBESAT AND P-POD DEPLOYMENT

California Polytechnic University and Stanford University began the CubeSat program in 1999. Since the first multiple launch CubeSat mission in 2003, over 80 universities, private companies, and government offices now develop CubeSat qualified systems. Basic requirements and a simple design allowed universities and research departments the ability to develop low-cost experimental satellites for orbital missions. CubeSats are built for insertion into the Pico-satellite Orbital Deployer (P-Pod) that uses a spring ejection system and is the standard interface to the launch vehicles. Together, these two systems are the foundation upon which the CubeSat defines its success.

Figure 15. CUBESAT Frame

Just as the ESPA dictates standardization and noninterference requirements for the primary payload, CubeSats operate under similar requirements. The CubeSat design uses standard interface documentation to ensure build requirements are followed. The P-Pod requirements ensure limited impact to launch vehicle power and are transparent to the primary payload. The standardization requirements mandate that the CubeSats are not active during ascent. Once the deployment sequence is initiated, a deployment switch then activates the power. The system also must be tested to ensure vibration stability and thermal vacuum bake-out to ensure proper out gassing. The mission of the Cal Poly CubeSat program is to strive to provide practical, reliable, and cost-effective launch opportunities for small satellites and their payloads. To do this, they provide the community with the following.

- A standard physical layout and design guidelines
- A standard, flight proven deployment system (P-Pod)
- Coordination of required documents and export licenses, if launching through Cal Poly
- Integration and acceptance testing facilities with formalized schedules
- Shipment of flight hardware to the launch site and integration to LV
- Confirmation of successful deployment and telemetry information

The P-Pod's primary focus is for safe housing of the CubeSats and assurance that they operate on a noninterference basis with the primary payload and the launch vehicle. CubeSats have produced great advancements in laboratory and technological programs by enabling payloads with low-level TRLs to be flown aboard a CubeSat. This allows programs to increase "the potential return for developers by providing on-orbit performance data at an earlier stage in development [52]."

Figure 16. Complete CUBESAT

The P-Pod and the ESPA Ring both act as facilitators behind satellite development. By creating a standard with which the satellites must adhere to for flight, standardization can be achieved and repeatable results can be attained. The P-Pod controls the CubeSat specifications by design. The system is a canister that holds one to three CubeSats with a total dimension of 10cm x 10cm x 30cm. By creating a canister design, the SV providers cannot push the specifications past the acceptable margins. If the canister is greater than the 10cm x 10cm x 30cm dimension, then it will not fit. The ESPA ring offers more flexibility for launch opportunities but also creates a dimensional box in which each SV must be contained.

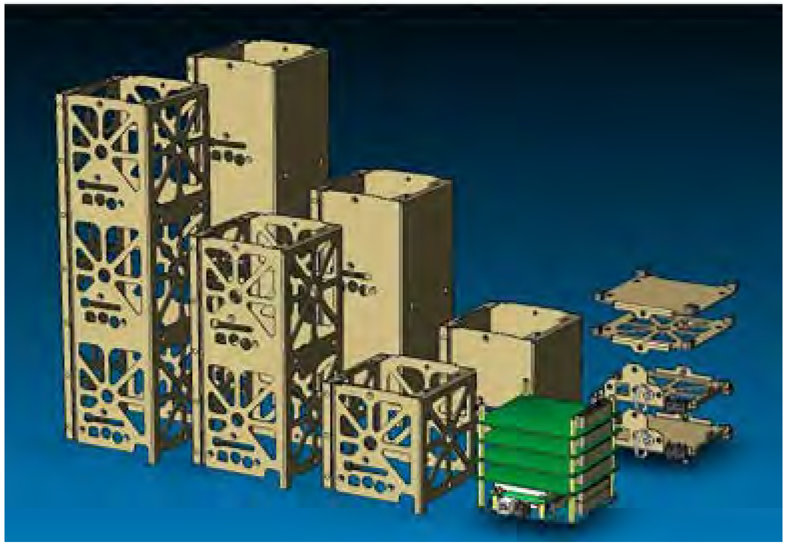

Figure 17. CUBESAT Variants

The P-Pod was developed with seven primary goals: [53]

- Protect the primary payload
- Protect the launch vehicle
- Protect the CubeSats
- Safely group multiple CubeSats for launch
- Eject CubeSats for safe deployment
- Increase Access to Space for CubeSats
- Provide standard interface to launch vehicle

Newman [54] states that the Naval Postgraduate School (NPS) is investigating DoD provided launch opportunities. This investigation will enable the CubeSat launcher to be placed aboard a government mission. In 2012, the National Reconnaissance Office will be launching a classified mission from Vandenberg AFB. The mission will fly with the ABC structure on the aft end of the Centaur upper stage that will carry the NPSCuL. NPSCuL was created by the Naval Postgraduate School and was developed as a multiple launcher configuration. The NPSCuL standard can carry up to 10 P-Pod deployers, whereas the Lite variant can carry up to eight deployers. The NPSCuL and NPSCuL-Lite provide CubeSat launches on U.S. EELV compatible launch vehicles and they are both

compatible with the ESPA ring. "In addition to the ESPA, NPSCuL-Lite is compatible with other secondary payload adapters, such as the new Aft Bulkhead Carrier (ABC) adapter being developed for Atlas V launch vehicles" [55]. Newman states, "the CubeSat is seeing growing acceptance in educational and research institutions due to its small size and relatively low cost and can provide NPS students with useful, short turnaround educational projects in satellite engineering and operations. CubeSat also show potential for us in rapid-prototyping and low-cost flight testing of advanced materials and systems and certain research payloads [54]." This flexibility allows the launcher to be attached to an ESPA mission and deploy 10–30 dedicated separate missions from just one attachment port on the system. This simple design and tight tolerance for the systems center of mass allows for it to be quickly integrated into the primary mission. If an ESPA secondary payload does not meet launch date, then another ESPA system can slide into the open slot and continue with the total system launch process.

Figure 18. NPSCuL-Lite

C. AEROSPACE CORPORATION SOLUTION INTEGRATION FOR ESPA

The Aerospace Corporation is a Federally Funded Research and Development Center (FFRDC), which is a nonprofit organization funded by the U.S. government to support programs with scientific research, analysis, and system acquisitions. Its research is to support the program's and public's interest while acting as an objective voice in the

pursuit of project understanding and success. To address the ESPA standardization concerns, Aerospace has been appointed as lead in identifying and resolving the mission integration issues. Aerospace is working to assist with the development of the EELV RUG and the Standard APL-ESPA-LV ICD documentation. Table 1 shows Aerospace's assessment of the current state compared to the way-ahead plan for the ESPA program [56].

MISSION ELEMENT	CURRENT STATE	WAY AHEAD PLAN
APL Qualification, Modeling, and Verification Data	►Varied APL qualification approaches required extra effort to evaluate for compatibility w/LV environments ►Lack of qualification standards to assure APL-LV compatibility	►Establish EELV Rideshare Specification with APL design requirements and qualification standards to assure compatibility with co-passengers and LV
Mission Interfaces	►Custom LV interfaces tailored to support APL requirements Variable interfaces & mission unique services	►Establish Standard APL-ESPA-LV ICD to eliminate APL interface variability ►Require APL to demonstrate compliance to standard ICD
SV Separation Systems & Attach H/W	►Variability in APL provided separation systems do not consistently assure mission compatibility & reliability ►Separation system re-design and additional qualification testing may be necessary	►LVC provide qualified critical flight hardware (separation systems, ESPA, harnesses, etc) with LVC assurance of reliable functionality
Mission Integration	►Multiple APL integration is very complex and challenging due to dissimilar requirements, interfaces, designs, & varied APL schedules ►Mission analyses approach not integrated with APL payload variability	►Single mission integration agent for the entire stack is more efficient as incremental effort to primary mission ►LVC systems engineering responsibility provides additional assurance of mission success
Launch Operations	Obtaining PPF facilities at launch site for APL processing is a major challenge	LVC to provide PPF for APL final processing & launch site support

MISSION ELEMENT	CURRENT STATE	WAY AHEAD PLAN
Schedule	Current LV integration lead times are too long to support APL mission Schedules—process geared for primary mission only	Redesign a process to permit APL launch assignment at L-24 Develop capability to permit APL re-assignment as late as L-12 months
Cost	APL integration cost is very high if performed like a primary mission High cost →Unused capacity	Cost reductions realized through interface & work scope standardization to reduce effort associated with APL missions

Table 1. Aerospace's Assessment of ESPA Processing

This comprehensive approach is designed to ensure a thorough understanding by all parties from development, planning, construction, and launch. This process reduces mission risks and ensures proper foresight is involved. With Secretary Gates' focus on reducing costs and finding answers to acquisition overruns, the activities performed by Aerospace will bring about a process that embraces incremental developmental activities and reduced costs.

1. Future Progress

Aerospace laid the foundation of the way forward by phasing the development for the ESPA activities. Four phases remain in Aerospace's vision for future success. Phase 2a is the next step in the process. This phase focuses on maturing the processes established and verified through the STP-1 mission into an engineering implementation plan. This creation of baseline work allows the STP office and the LVC to gain an accurate understanding of the work scope required for each APL and the missions as a whole. Furthermore, the work scope is allowing set standards and firm pricing models to be established making the marketability of the system better understood and embraced by potential APL programs. This phase also focuses on the launch manifests and the integration of the ESPA system on future missions based around excess margin. The current launch manifests track the progress of each mission and queue them into a forecast based upon mission readiness and availability of launch vehicles. By detailing the future missions, planners can determine what flight profile fits secondary payload

requirements and assignments can be made determining the best fit. With a desire to be more flexible, steps are being inserted into this phase to allow software, hardware, and payload changes as soon as Launch minus 12 months out (L-12). This standardization and preplanning will create a better responsive space system than the standard 24–36 month process.

Phase 2b is a concurrent process with Phase 2a but focuses on the documentation and written standardizations, making all parties better versed with the process ensuring compliance. In this phase, the development, approval, and publication of the ESPA RUG, and Standard ICD are completed. These two documents alone explain the steps performed and requirements by all parties.

Phases 3 and 4 are reserved for the mission kit development and fabrication. These phases continue to document the actual missions, which the ESPA ring is currently manifested on, allowing early flight designs. The DMSP-19 mission is manifested to carry the first Air Force operational ESPA adapter. This polar orbit satellite will be ideal for secondary payloads due to the low orbit and advantage for earth imaging, mapping, and sun synchronous missions.

2. Changing the Paradigm

Aerospace's alternate role is advocacy for the program. Support is always required for any program to succeed. By working with ULA, Aerospace hopes to assist with required changes allowing mission partners to better understand the processes ULA needs to prepare and execute missions. By developing a complete requirement set and issuing standardized flight hardware, a twofold approach of eliminating performance uncertainty and assuring mission compatibility will be achieved. By standardizing the processes, not only will mission integration be smoother, but also the integration process itself can continue to be redefined allowing improvements and flexibility to be achieved. Achieving flexibility not only reduces bottlenecks in the process, but it also creates missions, which are more conducive to an ORS environment. Some goals within the ESPA integration process are to drive changes in APL designation to 12 months [56]. By

reducing the timeline required, a more responsive launch manifest can be built allowing for rapid call-up of secondary payloads. Integration challenges pose the greatest barrier for successful realization of an ESPA standardized launch service. Two main drivers improve integration issues. The first is establishing integration "gates," which would allow oversight of the processes by grading the auxiliary payloads on their adherence. This consistency in the process would allow for an improved process and bottleneck reduction. The second integration challenge is to reduce integration costs. Integration activities are very expensive and could be a challenge for small programs to fund. By standardizing the costs and creating a fixed price approach, more entrants would emerge. Many universities would be able to advocate for funding if they had fixed prices to request. By establishing launch industry confidence in the processes, all parties would be more apt to approve an ESPA ring on more and more missions.

3. The Vision

Standard ESPA launch services will offer many benefits and have processes driven around accomplishing six visionary achievements. These achievements are:

- The first achievement is to provide frequent and regular launch opportunities to desired orbits with known capacities. The ESPA system is built upon this foundation. Having STP review the launch manifest for excess margin, missions will be tagged as ESPA capable and be configured with the ESPA ring, opening the mission to secondary payloads. This early awareness and orbit determination allows STP to match-mate early in the integration process so APL program managers have time to schedule the workflow.

- The second achievement is to shorten the lead time to enable near-term APL flight assignments and later APL swaps in the integration process. Following the guidelines set forth in the ESPA RUG and establishing clear communication lines early in the development process, shortened lead times, and APL swaps would become standard practice.

- The third achievement targets launch costs reduction from a typical single missions price ranging from \$7–10M per SV to about \$500K for a rideshare. This reduction would establish an inexpensive ride that would cover the integration and hardware support for each mission [57]. “The recurring cost for the ESPA units is estimated at \$600,000 plus \$50,000 for each secondary payload isolation system (if needed) [57].” The integration costs are already low, and then the cost spread between six missions drives the price into the realm where many small programs and universities can afford a ride.
- The fourth achievement is a policy that ensures no impact to the primary payload. This standardized launch service is intended to be aboard the majority of all EELV missions, and by operating in a manner which the primary payload performs testing and integration with an ESPA ring attached to the upper stage, the remainder of activities will be transparent and present no impacts to the primary payload.
- The fifth achievement is a culture change that builds in mission assurance into all aspects of the undertaking. Major General Pawlikowski explained mission assurance as both a process and culture in her article titled *Mission Assurance—A Key Part of Space Vehicle Launch Mission Success* [2]. She stated, “as a process, mission assurance is an iterative, continuous, technical, and management activity employed over the entire life cycle of a launch system to achieve confidence in mission success” [2]. As a culture, she noted, “each individual must assume personal accountability and responsibilities both to perform successfully their part of the mission and to work collaboratively with others to ensure the process functions as a whole” [2]. This mindset of a set process and cultural responsibility stresses the criticality of having a strong SV-LV-APL relationship.

Nothing about launch vehicles can be performed without a set methodical approach to best practices. Mission success is built around following and utilizing lessons learned.

- The sixth achievement to make ESPA rings successful is the establishment of matching the Atlas V and Delta IV capability. By creating a truly dual capable system, swaps cannot only be performed from mission to mission, but also from vehicle to vehicle allowing more options, more responsiveness, and more flexibility.

These six achievements, although currently just a vision for the system, are within reach if given support from leadership in government and industry. By leveraging the experience, history, and knowledge from the leaders in the industry, the current achievements can become instilled into the process and a standardized launch service offering rapid call up and limited impact can be possible. Since the rideshare is pushing technology and allowing less experienced entrants to the launch support mission area, assistance must be offered to ensure APLs understand their responsibilities and milestones ensuring the auxiliary payloads are in compliance with the requirements.

D. ASSISTANCE FOR AUXILIARY PAYLOADS DEVELOPERS

Understanding the audience is the first step to offering assistance for rideshare. Offering this capability to universities and small programs means giving them the tools required to perform smooth integration and testing of their payload. By standardizing the launch service, mission hardware kits can be developed giving them the interface upon which they can build the satellite. With the interface and umbilical hardware being offered, the ESPA RUG and the ICD will become the foundation of adherence.

1. EELV Mission Kit Hardware

To assist in the development of secondary satellites, a kit is being developed that will standardize the process for APLs. This standardized kit will aid the homogeny between the APL-ESPA-LV ICD. The hardware consists of the ESPA, ESPA-LV adapters, APL separation systems, electrical harnesses, connectors, umbilical, flight

instrumentation, and ground support equipment. The “nonstandard” APL requirements are considered mission unique items that the APL programs must supply. Some nonstandard requirements, which might be required by the APL, are power, hydrazine, and helium.

The LVC will provide engineering services and facilitate the process by providing the recurring APL integration analyses and support. The recurring launch site processing of hardware and integrated prelaunch operations will also be offered through the LVC. The Astrotech Payload Processing Facility at the Cape Canaveral Air Station is being used for many of the integration efforts.

2. EELV Rideshare Specification

EELV Secondary Payload Adapter Rideshare User Guide (ESPA RUG) is the single most important tool to inform the APL providers about their requirements in designing and fitting within the standardized parameters [58]. This document is being written by ULA and Aerospace and outlines the APL design criteria and requirements. The document should be viewed as the principal technical manual in the development of the APL by the program due to its ability to drive acceptance or denial of flight aboard an ESPA configured launch. Three focus areas within the document step future payload providers through the process. The guidance will be used to ensure a seamless transition from satellite development to mission integration. The three areas are mission requirements, environments, and ESPA secondary payload interface.

The mission requirements area assigns the APL to a future mission based on a comparison of the primary payload’s orbital insertion and the APL’s orbital insertion based on mission needs. The orbit required is based on the orbital elements of each mission’s requirements and a best match is identified. An example is the desire for a polar orbit mission vice an equatorial orbit mission. Once a suitable upcoming mission has been identified, the remainder of the mission area sets the stage for informational understanding of launch processing from vehicle separation, collision avoidance maneuvers, to the APLs required mass properties.

The environments section defines the specific satellite and space environment for payload processing, transporting, and RF emissions during launch and early orbit. This sections answers most questions initially asked by a spacecraft developer to assist with gaining a better understanding of the environment the APL will experience from mate to vehicle separation allowing subsystems and proposed components to be chosen to maximize the APL success. This section also shows the great extent the LVC goes through to ensure compliance and acceptance of APLs. This verification through testing and technical documentation is typically beyond the capabilities of most programs and assists the APL along the development and execution process. This section also defines the APLs “rules of engagement” by explaining what can and cannot be activated prior to APL separation. The APL must be powered off with no transmitting of data and no direct power connection between the APL and launch vehicle. The design of the APL must also be considered in regards to materials used to take out-gassing and total mass loss of condensable matter into consideration. The specification also describes gravitational forces, acoustics, vibrations, shock and thermal heating to assist the APL to design a their satellite, detailing how sturdy the satellites must be to survive and not risk injury or failure to the mission as a whole.

The ESPA secondary payload interface section describes the ESPA ring structure and the orientation of the coordinate system in relation to the Secondary Standard Interface Plane (SSIP). The approved dimensions for APL systems is 38”x28”x24” and can be increased due to some mission unique requirements at the approval of ULA. The interface used for attachment to the ESPA ring is through a circular ring with a diameter of 15 inches. The LVC will also supply the separation system, which is the Planetary Systems Corporation’s 15” Lightband Separation System. APLs must also comply with the Air Force Space Command Manual (AFSPCMAN) 91–710, Volumes 1, 3, and 6 and will rely upon a sponsoring agency to demonstrate compliance. Lithium-ion batteries must also be used in APL systems.

Together, these three sections set the basis upon which all current and future mission success will be measured. If properly followed, a trend can be set in development to allow the ESPA systems to be more successful and ensure future missions operate at a responsive state with faster call-up times.

3. Standard APL-ESPA-LV ICD

The ESPA ring drives four new requirements that add to the current Interface Control Documents (ICD). These requirements offer increased compliance and documentation to facilitate redundant processes for follow-on launches. With so many communities interested in developing APL satellites, a standardized ICD removes the fog of mission development and requests specific adherence to requirements. The four additional requirements build upon the currently successful ICD process and make a predictable progression from initial notification to mission integration. The first is the establishment of standard APL-ESPA-LV interface to eliminate mission variability. The second is the mechanical and electrical pass thru provisions for primary LV interface. The third is the Launch Vehicle Contractor (LVC) performance of the analyses as needed to substantiate interface design and flight envelope. The fourth is the Mission ICD, which is composed of the APL-ESPA-LV ICD and the Primary-LV ICD. The conjoining of documentation creates one master ICD. Reducing the integration time will make the system more responsive to space efforts allowing integration capabilities to touch the ORS focused initiatives to fewer than 12 months. Syncing up the APL systems with the Atlas V and Delta IV allow launch vehicles to be more flexible, providing greater successes with each mission.

E. SUMMARY

By taking the lessons learned from CubeSat and applying them to the ESPA program, much efficiency can be gained allowing the ESPA program to learn and build from prior program's experiences. Integration activities of the ESPA and APL are where these documented lessons will be most beneficial to program managers and system engineers. With Aerospace's assistance in the ESPA RUG and development of the ICD,

a more inclusive approach will be realized, using the current processes and applying a more precise plan for the system. Marking future missions as viable candidates for ESPA rings will lock missions into the manifest and get the program one step closer to achieving their goal of orbital operations. The mission kit is another offered incentive to make it possible and more simplistic for APLs to merge with the launch community. With the changing paradigms and visions in place, a more affordable approach can be offered to research and development programs, along with giving limited funded programs the opportunity to achieve on-orbit operations.

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V. CONCLUSION AND RECOMMENDATIONS

A. OVERVIEW OF EELV AND THE ESPA SYSTEM

This thesis began with one simple question; can the ESPA ring be so clearly defined and implemented that it becomes nearly transparent to the primary payload, making integration simple enough to gain program manager support and offer more frequent research and scientific missions to orbit? The answer is "yes" and with the ESPA RUG and ICD, it can be accomplished.

The ESPA ring's requirements are clearly defined and implemented so all parties will be able to develop the desired LV-SV-APL integration approach making it nearly transparent to the primary payload. The total sum approach makes integration simple enough to gain program manager support, offering more frequent research and scientific missions to orbit. With the top-down approach coming from leadership and the buy-in by the aerospace community, the program manager will continue to develop an appreciation for the desire to fly ESPA aboard all available missions with sufficient margin. The lessons learned from the difficulties in space acquisition are numerous, and gaining a better understanding of the current state of acquisitions and requirements will allow decision makers to implement novel ideas to improve upon the current and clearly broken acquisition process.

Taking into account space operation complexities, high developmental costs, and low launch rates, better decisions can be made through maximizing the use of launch vehicle margin for the purpose of advancing technology, which will ultimately result in shortened acquisition schedules. The 2001 Space Commission noted that, "to achieve national security objectives and compete successfully internationally, the U.S. must maintain technological leadership in space. This requires a healthy industrial base, improved science and technology resources, an attitude of risk-taking and innovation, and government policies that support international competitiveness. In particular, the government needs to significantly increase its investment in breakthrough technologies to fuel innovative, revolutionary capabilities. Mastery of space also requires new

approaches that reduce significantly the cost of building and launching space systems. The U.S. will not remain the world's leading space-faring nation by relying on yesterday's technology to meet today's requirements at tomorrow's prices [19]."

With the simple design, strict requirements, and non-interference basis approach, the ESPA system offers a new realm within which innovative advancements, small satellites, and TRLs can continue to advance U.S. systems by offering operationally verified systems. The initial beginnings have had upper level leadership support, while program managers hesitate with the idea of adding complexity to their systems. Due to the success of STP-1 and LCROSS, the future looks promising delivering more opportunities for ESPA to continue to show the benefits of flying secondary missions.

GAO studies, which followed acquisition programs through maturity, learned that five of six space systems (when cost estimates were developed) had program officials and cost estimators who believed that the technology critical to program success would be mature and available. This belief proved to be incorrect and resulted in a realization that the technology issues ended up being more complex than initially understood, resulting in cost, schedule and technical overruns. For example, on the NPOESS program, DoD and the Department of Commerce committed funds for the development and production of satellites before the technology was mature. It was later determined that only one of 14 critical technologies were mature at program initiation and one technology was determined to be even less mature than initially thought after the contractor conducted more verification testing. The program has since been beset by significant cost increases and schedule delays due in part to technical problems, such as the development of key sensors, which was one reason why the program was dissolved. Thus, the DoD and Weather community must now go their own way in developing separate weather satellite constellations.

"For the GPS IIF program, the cost estimate was built on the assumption that the military code signal being developed would fit on a single microchip. However, once development started, interface issues arose and the subcontractor had to move to a two-microchip design, which took eight months to resolve and increased cost to the program

[59].” In hindsight, these easy to comprehend issues seem to be simple to fix; however, the solutions and technology evolutions, which finally restored the acquisition approach, came too late and with too much of a cost overrun to continue justifying the exorbitant cost overruns, resulting in some systems experiencing Nunn-McCurdy breaches and even project termination.

The ESPA system continues to prove its benefits to the scientific community by providing more opportunities for on orbit research opportunities. These opportunities can be used to advance the technical readiness of many payload components. With each mission's determination to use an ESPA system, great results are produced justifying the implementation onto future missions. With each success, comes greater support, which validates the utility of the simple design. Turning this flight proven system into a standard integration item is the next challenge for ULA, LRSD, and SDTD. With continued leadership support, APL adherence to integration requirements and successful missions, future manifests can represent a whole suite of launches packed with multiple missions and results benefiting a much larger community, evolving technology and gaining a better understanding of ideas, which are only in theory, due to the ability to provide low-cost orbital insertion and true testing in the operational environment of space.

B. FUTURE DEVELOPMENT DIRECTION

From the frequent Nunn-McCurdy breaches in space programs to the continual negative perception placed on developing space programs in the defense community, it is time for a change and time for acquisition programs to verify capabilities prior to contract awards. The old mindset of overstating requirements and underestimating costs to ensure program approval must end. With the current trend of billion dollar programs doubling or tripling, space programs might find themselves in a situation that a follow-on system will become impossible to afford and even justify. The reins must be pulled in, and it is a necessity that cost and schedule be accurately planned and followed throughout the life cycle of the systems. U.S. leadership is also noting, “Significant cost growth and schedule delays in many critical space system programs have caused senior DoD and

Intelligence Community leadership to question our nation's ability to acquire and sustain national security space systems [60]." Not only did the concerns get noted, but also, the threats have been put into effect by canceling programs. Space Radar, TSAT, SBIRS, and NPOESS are just a few of the space programs that have either been canceled or had their requirements slashed in an attempt to reduce the hemorrhaging of funds and delays.

On 1 February 2010, the White House sent a message loud and clear to the NPOESS program when it ended the "troubled civil-military weather satellite program [61]." The decision has been made that NPOESS will no longer stand as a single program, but will instead be two separate satellites systems serving military and civilian users. "The NPOESS program has for years been plagued with cost overruns and delays, and the program's tri-agency management structure has been cited as a major contributor to the problem [61]." As these programs learn all too late, "the chief reason for developmental problems is the encouragement within the acquisition environment to attempt overly ambitious and lengthy product developments, which are referred to as revolutionary or big bang acquisition programs that embody too many technical unknowns and not enough knowledge about the performance and production risks they entail [62]." With the mostly unwanted interest in the managing of space programs, the areas of concern have been flagged and can now begin to be questioned or verified for technical readiness. For programs that have too many components with low TRLs, the ESPA ring can provide opportunities for relatively low cost on-orbit component tests to help avoid the problems described above.

C. SPECIFIC RECOMMENDATIONS

Having all parties working together and following the established requirements laid out in the ESPA RUG and ICD, the integration difficulties can be relieved and a safe consistent process can be repeated allowing the high cost of launch to bring more benefits to multiple programs and users. With the STP-1 mission, there were many first time integration challenges and even first time maneuver requirements for the Centaur upper stage. Even as a first flight, it was clear to see the benefits outweighed the challenges, allowing five unique spacecraft perform nine total experiments through a single launch

vehicle costing approximately $90M. That single launch would be equivalent to seven launches spanning a year's worth of launches on the EELV manifest and costing approximately $700M in launch vehicle cost.

Directing APLs to develop a mass simulator early in the process mitigates the problems associated with a secondary payload missing the mission. These simulators allow developers to continue working on their SV issues much closer to the launch date, keeping the primary payload and remaining secondary payloads moving towards launch.

ESPA operates with the goal of not interfering with the primary payload and has established requirements making this possible. There are many strict requirements in the ESPA RUG and ICD on how the SV must be built which further facilitates this noninterference. The systems must be deactivated during integration and ascent. In addition, by laying out the specific "box" dimensions that a secondary payload must fit within, the integration standardization process is much easier for the APL program. To ensure additional safety, the primary payload is always separated first, and then the upper stage moves away from the primary payload's orbit prior to beginning deployment of the secondary payloads.

The successful STP-1 mission and the LCROSS mission opened new doors of understanding into what acceleration potentials can be achieved for future missions demanding a more ORS approach. With the standardization and lessons learned, more focus will be placed on orbital loads allowing for more rapid software development creating a much more ORS friendly responsiveness. The mass simulator, early integration and loads analysis, lessons learned, and more interested participants will allow for a "hot spare" approach to be realized. This backup is just one of the benefits already discussed in the ORS community.

D. SUGGESTED AREAS FOR FUTURE STUDY

This thesis discussed the historical and current acquisition of space programs and launch operations of the United States. The primary goal is to develop a better appreciation of why secondary payloads are viable options for reduced costs, increased

TRLs, and flexibility for current and future acquisition programs. Future study into costs, orbital dynamics, flight loads, and manifesting missions should be further studied to clarify and standardize the strict requirements placed on secondary payloads. With continued research, proven missions, and rideshare forums, progress can be made to better develop cost models and flight loads making ESPA integration more seamless.

This thesis is not an attempt to say orbital dynamics and loads are simple or without challenges when integrating an ESPA system, but it is intended to indicate that it is possible; that the challenges are outweighed by the benefits each mission success brings to the scientific community and DoD. Research is ongoing in the challenging areas of flight dynamics and manifesting. These areas require further research, and they themselves are worthy of countless thesis and research topics.

Although much research has been accomplished to have the ESPA system proven, more is still required to make it affordable, regular, and standardized. The following ideas are recommended for consideration based on the research conducted in this thesis.

- Enforce standardization issues early in the process

Beginning with a solid foundation of requirements and enforcing a strict standardization approach, APLs will gain the respect required to earn a position on future missions.

- Enable secondary payload programs to participate in the requirements process

When reviewing secondary payload proposals, all participants will understand the benefits the research will provide. In addition, the primary payload developer can provide details about the requirements process and the schedule so all secondary payload developers can be prepared for the launch at the planned date.

- Open the launch manifest to welcome secondary payloads by flagging known margin and orbits

With launch manifesting occurring typically five to three years before launch, flagging available margin early on will allow payload providers ample time to develop and follow the required documents.

- Create an environment in which program managers see it as their duty to search for and support missions with available margin to support secondary payloads

Removing the prototype stigma from the ESPA ring and making standard integration hardware will allow program managers to view the ESPA ring as just another requirement in the launch service.

- Continue to improve upon team communication

The space industry is large and diverse. More communication and openness of all parties will allow for greater innovation.

- Prove technology maturity in operational environment

The final goal of most laboratory research is to test the system in the operational environment. By making low-cost rideshare avenues available, many programs that would never garner the opportunity to enter space will now find themselves achieving orbit and taking their research to new levels of technology readiness.

E. CHAPTER SUMMARY

This chapter is intended to leave the reader with final thoughts and considerations into the benefits offered by integrating an ESPA onto future missions. An appreciation of the acquisition challenges facing many programs can be overcome by progressing TRLs prior to contract awards and source selections. The lessons learned from failed programs are extensive and most areas points to the benefits an ESPA ring offers. The GAO has extensively reported requirements, which if followed early in the system life cycle, will result in greater chances of success. As noted, this thesis is not an attempt to dig deep into the flight dynamics and loads issue resulting from changing the balance of spacecraft

weight and center of gravity. However, if early manifesting is accomplished, and APLs follow the required procedures, early integration efforts will allow smooth transitions along the system's development.

LIST OF REFERENCES

[1] *Delta IV, Payload Planners Guide (PPG),* United Launch Alliance, September 2007 http://www.ulalaunch.com/site/pages/Products_DeltaIV.shtml.

[2] E. Pawlikowski, “Mission assurance—A key part of space vehicle launch mission success.” *High Frontier Magazine*. Air Force Space Command (AFSPC) Journal, August 2008, v. 4.

[3] J. A. Stephenson, “Taxpayers, space community benefit from innovative “ESPA” ring adapter,” Space and Missile Systems Center Public Affairs, Los Angeles AFB, September 16, 2006 http://www.afspc.af.mil/news/story.asp?id=123022103.

[4] H. R. Hertzfeld, R. A. Williamson, and N. Peter, “Launch vehicles: An Economic perspective” *Space Policy Institute*: The George Washington University, September 2005.

[5] S. Clark, “Air Force says Constellation cuts could raise launch costs,” *Spaceflightnow.com* March 2010, http://www.spaceflightnow.com/news/n1003/15eelvcosts.

[6] Air Force Space Command. “ORS Office Stands up in Kirtland,” *377th Air Battle Wing*, May 2007 http://www.afspc.af.mil/news/story.asp?id=123053775.

[7] 2007 Plan for operationally responsive space: “A report to congressional defense committees” Source May 2007.

[8] S. Magnuson, “Military looks to small satellites as cost for large spacecrafts grow” NDIA’s Business and Technology Magazine, http://www.nationaldefensemagazine.org/archive/2010/July/Pages/MilitaryLookstoSmallSatellites.aspx, July 2010.

[9] Government Accountability Office. Space Acquisition, “Actions Needed to Expand and Sustain Use of Best Practices Statement of Cristina T. Chaplain, Director Acquisition and Sourcing Management Team,” *Testimony before the Subcommittee on Strategic Forces*, Senate Committee on Armed Services, April 19, 2007.

[10] COMSTAC “2008 Commercial Space Transportation Forecasts.” *FAA Commercial Space Transportation (AST) and the Commercial Space Transportation Advisory Committee (COMSTAC).* May 2008.

[11] Space Transportation Costs, “Trends in Price Per Pound to Orbit 1990–2002,” *Futron White Paper* September 6, 2002.

[12] SMC Public Affairs “Air Force awards EELV Boeing ELC contract,” *Air Force News*, Los Angeles AFB. November 17, 2006 http://www.losangeles.af.mil/news/story.asp?id=123032296.

[13] ArianeSpace “2009 annual report,” *ArianeSpace Service and Solutions*, 2010 http://www.arianespace.com/about-us-corporate-information/annual-report.asp.

[14] ArianeSpace “2008 annual report.” *ArianeSpace Service and Solutions,* 2009 http://www.arianespace.com/about-us-corporate-information/annual-report.asp.

[15] E. Kyle, “Space launch report reliability,” *Space launch report* December 8, 2010 www.spacelaunchreport.com/reliability2010.txt.

[16] I. O’Neill. “Space tourist Richard Garriot launches toward space station” October 2008. *Universe Today* http://www.universetoday.com/2008/10/13/space-tourist-richard-garriot-launches-toward-space-station.

[17] PRNewswire.com. “United launch alliance begins operations.” December 2006. http://www.prnewswire.com/news-releases/united-launch-alliance-begins-operations-55781087.html.

[18] J. S. Goodwin, and P. Wegner, “Evolved expendable launch vehicle secondary payload adapter—Helping technology get to space” *AIAA Space 2001 Conference* Commission to Assess United States National Security Space Management and Organization, January 11, 2001.

[19] Space Commission “The Commission to Assess United States National Security Space Management and Organization,” January 11, 2001.

[20] Government Accountability Office, “Space Acquisition—DoD needs to take more action to address unrealistic ICE of Space Systems,” *Report to Subcommittee on Strategic Forces, Committee on Armed Services, House of Representatives*, November 2006.

[21] Government Accountability Office Testimony Before the Subcommittee on Strategic Forces, “Space Acquisitions DoD Delivering New Generations of Satellites but Space System Acquisition Challenges Remain” *Committee on Armed Services U.S. Senate,* May 11, 2011.

[22] W. Allard, United States Senator, “Address to the National Defense Industrial Association,” *2005 Space Policy and Architecture Symposium*. September 23, 2005 http://www.globalsecurity.org/space/library/news/2005/space-050923-ndia-allard.htm.

[23] Government Accountability Office. Testimony Before the Subcommittee on Strategic Forces, "U.S. Senate Space Acquisitions-DoD Faces Substantial Challenges in Developing New Space Systems" *Committee on Armed Services*, May 20, 2009.

[24] R. M. Gates, "Defense Budget Recommendation Statement," *U.S. Department of Defense Office of the Assistant Secretary of Defense Public Affairs,* April 6, 2009 http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1341.

[25] J. Mathis, T. Marrujo, & C. Weiss, "Small Satellite Access to ESPA Standard Service" 2007.

[26] SMC/XR, "Leveraging Excess Launch/Spacecraft Margin," *SMC Industry Day Presentation*, April 16, 2008.

[27] Headquarters AFSPC, Directorate of Plans and Requirements "Operationally responsive space/launch vehicle initial capabilities document" Draft. Peterson AFB, CO.

[28] Government Accountability Office, "Space Acquisitions: DoD is Making Progress to Rapidly Deliver Low Cost Space Capabilities, but Challenges Remain," GAO report number GAO-08–516, April 25, 2008.

[29] R. M. Sega and J. E. Cartwright, "2007 Plan for operationally responsive space: A report to congressional defense committees" *U.S. Department of Defense,* April 17, 2007.

[30] J. C. Mankins, "Technology Readiness Level, A white paper," *Advanced Concepts Office*, Office of Space Access and Technology NASA, April 1995.

[31] Defense Procurement and Acquisition Policy Office, Under Secretary of Defense AT&L. "Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment." Version 1.0. January 31, 2003.

[32] E. Tauscher, "U.S. House Representative, Hearing on the fiscal year 2008 budget request and status of space activities," Address to the Subcommittee on Strategic Forces, *Committee on Armed Services*, House of Representatives. Washington. March 5, 2008. http://www.fas.org/irp/congress/2008_hr/space.pdf.

[33] Government Accountability Office website, *About Government Accountability Office*, March 10, 2010. http://www.gao.gov/about/index.html

[34] Government Accountability Office, "DoD Poised to Enhance Space Capabilities, but Persistent Challenges Remain in Developing Space Systems," Testimony Before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, *Statement of Cristina T. Chaplain, Director Acquisition and Sourcing Management*, March 10, 2010.

[35] Boeing website, "Wideband Global SATCOM (WGS) Factsheet, March 2009 http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/wgs_factsheet.html.

[36] DARPA, "Orbital express fact sheet" 2007. http://archive.darpa.mil/orbitalexpress/index.html.

[37] D. E. Lee, "Space reform." *Air and Space Power Journal*, volume 18(2), pp. 103–112. September 2004 http://www.airpower.maxwell.af.mil/airchronicles/apj/apj04/sum04/lee.html.

[38] NRL Press Release, "NRL SHIMMER and CITRIS Experiments Launched on STPSat-1 to Study Earth's Atmosphere," March 9, 2007. http://www.nrl.navy.mil/pao/pressRelease.php?Y=2007&R=11–07r.

[39] AeroAstro. "STPSat-1 fact sheet" Comtech AA, 2007. http://www.aeroastro.com/index.php/program-heritage/stpsat-1.

[40] N. Ambrosiano, "Cibola flight experiment launches on Atlas V rocket" *Los Alamos National Laboratories*, March 9, 2007.

[41] P. Tisa and P. Vergez, "Performance analysis of control algorithms for FalconSat-3," *16th AAS/AIAA space flight mechanics conference*, Tampa FL. AAS Publications Office, January 22–26, 2006.

[42] NASA. "MidSTAR-1 successful technologies may be revolutionary," NASA February 19, 2008. http://www.nasa.gov/centers/goddard/news/topstory/2008/midstar.html.

[43] N. Atkinson, "LCROSS confirms "buckets" of water on the moon," *Universe Today*, November 13, 2009.

[44] S. Korris, "Northrop Grumman Ships LCROSS to NASA's Kennedy Space Center," *Northrop Grumman Aerospace Systems,* Globe News Wire, February 17, 2009.

[45] J. Dino, "LCROSS impact data indicates water on moon," NASA, November 13, 2009.

[46] M. Scherbarth, D. Smith, A. Adler, J. Stuart, and G. Ginet, "AFRL's Demonstration and Science Experiments (DSX) mission," Solar Physics and Space Weather Instrumentation III. *The International Society for Optical Engineering*. 2009.

[47] T. D. Chavez, M. J. Barrera, and M. H. Kanter, "Operational satellite concepts for ESPA rideshare," 2007.

[48] M. W. Wynne, "EELV Secondary Payload Adapter (ESPA) Policy," *Memorandum for AFSPC/CC*, Secretary of the Air Force. 2008.

[49] Kirtland AFB, "SDTD Fact Sheet," 2011. http://www.kirtland.af.mil/library/factsheets/factsheet.asp?id=6881.

[50] SD PAMPHLET 800–11, "Acquisition Management, Guide For Independent Readiness Reviews Expendable Launch Vehicle (ELV) Missions," *Headquarters Space Division (AFSPC),* Department of the Air Force, March 10, 1986.

[51] A. Toorian, E. Blundell, J. Puig-Suari, and R. Twiggs, "CubeSats as responsive satellites," AIAA 3rd Responsive Space Conference, 2005.

[52] S. Greenland, and C. Clark, "Cubesat Platforms as an on-orbit technology validation and verification vehicle," *Pestana Conference Centre* - Funchal, Madeira- Portugal, May 31-June 4, 2010.

[53] A. Chin, R. Coelho, L. Brooks, R. Nugent, and Dr. J. Suari, "Standardization Promotes Flexibility: A Review of CubeSat's Success," Aerospace Engineering Department, California Polytechnic State University, 2008.

[54] J. H. Newman, D. Sakoda, and R. Panholzer, "CubeSat launchers, ESPA-rings, and education at the Naval Postgraduate School," *21st Annual AIAA/USU Conference on Small Satellites*. Logan, Utah: AIAA. 2007.

[55] California Innovation Corridor. "Naval Postgraduate School CubeSat Launcher (NPSCuL) space-available manifesting process and requirements," Version 1. Monterey, CA: *Naval Postgraduate School Space Systems Academic Group*, 2008.

[56] C. Pao, and R. Kim, "EELV Secondary Payload Adapter ESPA Standard Launch Service," *Aerospace Corporation*, NRO/AIAA Space Launch Integration Forum, July 16, 2008.

[57] S. Haskett, L. Doggrell, E. Fosness, D. Sciulli, T. Meink, and J. Maly "EELV Secondary Payload Adapter (ESPA) ," 13th AIAA/USU Conference on Small Satellites, 1999.

[58] Evolved Expendable Launch Vehicle Secondary Payload Adapter Rideshare Users Guide (ESPA RUG), May 2010.

[59] Government Accountability Office, “Space acquisitions: DoD needs to take more action to address unrealistic initial cost estimates of space systems,” GAO-07–96, *Report to Subcommittee on Strategic Forces,* Committee on Armed Services, House of Representatives. Washington, DC. November 2006.

[60] Young, “Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs,” Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Washington, D.C. May 2003.

[61] T. Brinton, “White House dissolves NPOESS partnership in blow to Northrop Grumman,” NPOESS. February 2010.

[62] Statement of Michael J. Sullivan, Director Acquisition and Sourcing Management, “DoD Must Balance Its Needs with Available Resources and Follow an Incremental Approach to Acquiring Weapon Systems,” *Testimony Before the Committee on Armed Services,* U.S. Senate, Defense Acquisitions, GAO GAO-09–431T, March 3, 2009.

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